Broker-based Service-oriented Content Adaptation Framework

by

Mohd Farhan Md Fudzee
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Abstract

Electronic documents are becoming increasingly rich in content and varied in format and structure. At the same time, user preferences vary towards the contents and their devices are getting increasingly varied in capabilities. This mismatch between rich contents and user preferences along with the end device capability presents a challenge in providing ubiquitous access to these contents. Content adaptation is primarily used to bridge the mismatch by providing users with contents that is tailored to the given contexts e.g., device capability, preferences, or network bandwidth. Existing content adaptation systems employing these approaches such as client-side, server-side or proxy-side adaptation, operate in isolation, often encounter limited adaptation functionality, get overload if too many concurrent users and open to single point of failure, thus limiting the scope and scale of their services. To move beyond these shortcomings, this thesis establishes the basis for developing content adaptation solutions that are efficient and scalable. It presents a framework to enable content adaptation to be consumed as Web services provided by third-party service providers, which is termed as "service-oriented content adaptation". Towards this perspective, this thesis addresses five key issues – *how to enable content adaptation as services* (service-oriented framework); *how to locate services in the network* (service discovery protocol); *how to select best possible services* (path determination); *how to provide quality assurance* (service level agreement (SLA) framework); and *how to negotiate quality of service* (QoS negotiation). Specifically, we have: (i) identified the key research challenges for service-oriented content adaptation, along with a systematic understanding of the content adaptation research spectrum, captured in a taxonomy of content adaptation systems; (ii) developed an architectural framework that provides the basis for enabling content adaptation as Web services, providing the facilities to serve clients' content adaptation requests through the client-side brokering; (iii) developed a service discovery protocol, by taking into account the searching space, searching time, match type of the services and physical location of the service providers; (iv) developed a mechanism to choose the best possible combination of services to serve a given content adaptation request, considering QoS levels offered; (v) developed an architectural framework that provides the basis for managing quality through the conceptualization of service level agreement; and (vi) introduced a strategy for QoS negotiation between multiple brokers and service providers, by taking into account the incoming requests and server utilization and, thus requiring the basis of determining serving priority and negotiating new QoS levels. The performance of the proposed solutions are compared with other competitive solutions and shown to be substantially better.

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Chapter 1

Introduction

The rapid development of digital media technologies has enabled the emergence of novel media content types for various domains including e-Commerce, e-Education, and e-entertainment. As a result, there is a phenomenal growth in consumable electronic information on subjects such as entertainment, security, education, and technical documentation targeted to diverse users in the form of content and services.

While online documents are becoming increasingly rich in content and varied in format and style, the original content is normally developed for a specific platform and is naturally made-up of media objects of different types with complicated structure and layout [1]. For instance, most of existing Web content is originally designed for desktop displays. At the same time, client devices are getting increasingly varied in their capabilities (e.g., processing power, input and output facilities). Therefore, direct content delivery to handheld devices without layout adjustment often leads to disorganization of information [2]. Moreover, as depicted in figure 1.1, not every handheld device can play all media types. For example, a non-multimedia mobile phone cannot play continuous video clips, while only H.264, MPEG-4 and M-JPEG formats are currently supported for iPhone video playback. As such, some widely employed video formats such as MKV and FLV will require format conversion or additional player before they can be played on iPhone.

Although content providers are under constant pressure to make content available in a variety of formats and for a variety of purposes [3], the mismatch between rich contents and the end devices capability coupled with specific users preferences

continues to present a challenge in providing seamless and ubiquitous device-independent access to the online electronic contents to interested users. It becomes apparent that a mechanism for dynamically transforming the original content to suite the end device and user's preference as appropriate is required.

unable to view the video

PDA view

Desktop view

Figure 1.1: Non technical view of content adaptation issue.

1.1 Motivation and Scope

Content adaptation has emerged as a potential mechanism to address some of the problems arising from the content-device mismatch [2, 4, 5, 6, 7, 8, 9, 10, 11]. Although many content adaptation approaches have been proposed, most of them tend to be fully or partially centralized. Problems with centralized adaptation scheme such as scalability and single-point failure are well known [12]. In order to address these problems, the idea of establishing content adaptation as a service that allows the use of a large number of adaptation mechanisms located in many places in the network has recently been advocated [11, 13, 14, 15]. Thus, the in-depth exploration of service-oriented architecture for content adaptation together with the enabling mechanisms is required to provide flexible and scalable content adaptation services. Unfortunately, analysis of the previous research efforts [5, 14, 16, 18] in this context reveals that there has been only a

few rudimentary frameworks exist. Also, in order to provide an efficient service-oriented content adaptation system, enabling mechanisms such as service discovery, path determination and service quality assurance are essential. However, these mechanisms have not been fully explored. The reason for this lack of progress is due to the complexity of the technological problems that need to be addressed in the practical context.

1.2 Research Significance

The content adaptation challenge is how to make the original contents readily available on a wide range of access devices for interested clients. One way to address this problem is by creating and maintaining different format of the original content suitable to the targeted access devices. However, keeping multiple copies of the original content will lead to tremendous overhead and places unwieldy burden on to the content authors.

Thus, what is required is a content adaptation system with the appropriate logic to analyse the content and all aspects of the adaptation contexts and formulate the content adaptation strategy accordingly. There are many content adaptation approaches that generate any content version from one single original version [3, 6, 7, 8, 9, 10, 16]. A request may require multiple content adaptation tasks that can lead to the requirement of multiple adaptation strategies including cross-media adaptation (e.g., media conversion, translation, summarization, and integration). None of existing standalone content adaptation systems is able to completely serve this request. Moreover, building one system that capable of providing various adaptation strategies is inefficient and costly.

On the other hand, there are many service providers offering a variety of content adaptation that can be loosely coupled. Therefore, the solution for these services is to cooperate with each other to completely serve the request that they cannot attain individually. A platform that enables such interconnection and interoperation is required. Thus, a greater scale as well as service quality can be achieved.

1.3 Research Problems

This thesis tackles the research challenges in relation to the development of scalable and efficient content adaptation solutions by enabling coordination and cooperation between

multiple service providers. While service-oriented content adaptation is appealing, the challenges in adopting it include architecting a system that analyses the required content adaptation tasks and distributes these tasks to the potential service providers. In particular, we identify and investigate the following five research issues:

- *How to enable content adaptation as services.* The platform that allows content adaptation to be performed as services by external service providers. This should include the essential mechanisms to manage client requests and service provider advertisements.

- *How to locate services in the network.* The protocol used to locate potential content adaptation service from the network. Such a protocol must take into account searching space, searching time, matching category of services and physical location of the service providers.

- *How to select best possible services.* The decision making mechanism used for choosing the best possible services to serve a request, given that multiple services can potentially perform a particular task.

- *How to provide quality assurance.* The framework used to manage service agreement between service providers and clients. It should formally specify the creation, monitoring and enforcement of such an agreement.

- *How to negotiate quality of service.* A mechanism to negotiate QoS before the agreement being settled. Service provider should ensure that the QoS they advertised is deliverable to avoid potential violation.

1.4 Research Objectives

To achieve the research aim, three main research objectives are identified and need to be fulfilled:

1. To develop the taxonomy of content adaptation systems and to determine the issue pertaining to existing content adaptation systems that have not been fully explored.

2. To design a conceptual framework for the service-oriented content adaptation based on the identified components and functions required for a complete content adaptation system.

3. To design, develop and analyse the enabling mechanisms, i.e. service discovery, path determination and service level agreement, in relation to service-oriented content adaptation.

1.5 Methodology

The proposed work will be carried out based on the experimental computer science method [17]. This method examines the research work to demonstrate two important concepts: proof-of-concept and proof-of-performance.

To demonstrate the proof-of-concept, some important steps were performed. First, the research area within content adaptation is critically reviewed to provide the overview that leads to the formulation of valid problem statements. From this review, the research work is justified. Then, the proposed conceptual framework of the service-oriented content adaptation architecture is designed and analytically analysed.

Proof-of-performance is demonstrated by conducting the implementation for the service discovery protocol, path determination and QoS negotiation using simulations. In those simulations, various parameters and workloads were used to examine and demonstrate the viability of the proposed solutions compared to the similar competitive solutions. Also, analytical analysis of some proposed algorithms is performed to evaluate the correctness.

1.6 Research Contributions

We detail the thesis contributions as the following:

1. *Content adaptation taxonomy*. This thesis presents a taxonomy of content adaptation systems. It investigates related concepts, describes the design themes and identifies implementation components required. The presented taxonomy is mapped to representative content adaptation systems to demonstrate its applicability. Also, the mapping assists to perform a gap analysis in this research field.

2. *Broker-based* s*ervice-oriented content adaptation framework*. The thesis introduces an architectural model for service-oriented content adaptation. It describes the essential components, interaction sequences, and related protocols

for enabling content adaptation as services. An analytical analysis is conducted to demonstrate the framework applicability.

3. *Service discovery protocol*. The thesis investigates and presents the protocol to locate available content adaptation services from the network. Along with the derivation of the discoverability performance metric, extensive simulations have been conducted to study the performance of the service discovery protocol in this regards. The proposed protocol is able to quickly terminate the search when specified conditions are achieved. Also, the analytical analysis proved the completeness and the accuracy of the protocol.

4. *Path determination mechanism*. The thesis presents the mechanism to determine the best possible services based on the single objective assignment function. The proposed mechanism is evaluated through simulations in term of service selection execution. The mechanism is demonstrated to meet its objective i.e., appropriate service QoS value assignment.

5. *SLA framework*. This thesis introduces a framework for managing service level agreement in relation to content adaptation. It describes the interrelated phases and the essential mechanisms. Then within the framework, a QoS negotiation strategy is presented. The proposed negotiation strategy is evaluated through simulations and is shown to increase SLA settlement, and reduce request rejection and potential SLA violation as well.

To summarize, the work presented in this thesis is in line with the current trends that enable multitude content adaptation services without having to build a dedicated infrastructure [5, 14]. Therefore, it is our thesis to present service-oriented content adaptation solutions that are scalable and efficient.

1.7 Thesis Organization

The chapters of this thesis are derived from various papers published during the PhD candidature. The remainder of the thesis is organized as the following:

- *Chapter 2: Content Adaptation Systems.* This chapter provides an in-depth analysis and overview of existing content adaptation systems, presented within a comprehensive taxonomy.

- *Chapter 3: Service-oriented Content Adaptation*. This chapter presents an architecture to enable content adaptation to be consumed as services. It describes the key components to realize service-oriented content adaptation.

- *Chapter 4: Service Discovery Protocol*. This chapter presents a service discovery protocol in relation to service-oriented content adaptation. The simulation results are discussed as well.

- *Chapter 5: Path Determination*. This chapter presents a path determination mechanism in relation to service-oriented content adaptation and the related simulation results.

- *Chapter 6: Service Level Agreement*. This chapter presents a framework for managing service level agreement and QoS negotiation strategy in relation to service-oriented content adaptation. The simulation results of the negotiation strategy are discussed as well.

- *Chapter 7: Conclusion and Future Directions*. The concluding chapter provides a summary of contributions and a future research challenges.

Chapter 2

<u>Content Adaptation Systems</u>

The ever-increasing amount of electronic information coupled with proliferation of diverse and heterogeneous devices, data sources, user preferences and networks has significantly increased the demand of content adaptation. This makes content adaptation as a thriving research field. There are many projects focused on the content adaptation being introduced constantly. This chapter provides an in-depth analysis of current content adaptation technologies, organized as a comprehensive taxonomy. The taxonomy provides a basis for categorizing related solutions and being mapped to a few representative systems to demonstrate its applicability. Then, a "gap analysis" is performed from the presented literature and used to position the thesis.

2.1 Introduction

Today, computing is no longer limited to a specific location using desktops devices, but can be done on laptop computers and information appliances (e.g., PDAs, smart phones, etc.) from anywhere at any time. This new computing platform is known as pervasive or ubiquitous computing and has recently attracted a lot of attention. However, the characteristics of this paradigm shift (including device heterogeneity, limited device capability, and user's high mobility) bring about new challenges in the delivery of information, content and services in these environments. This makes the ability to adapt information, content and services to a diversity of computing devices a key to pervasive computing.

Specifically, devices, standards and software develop rapidly, but still often independently of each other [15]. This creates problems in terms of content suitability. Also, in pervasive environment, user and system-level applications must execute subject to a variety of resource constraints that generally can be ignored in modern desktop environments. Moreover, Web applications are designed with desktop platform in mind that usually contains rich media content and authored in a single version. In order to increase the usability of mobile Internet services, content adaptation is required. Also, the emergence of these requirements (e.g., device heterogeneity, user preferences, rich content) demands efficient content adaptation architecture. Designing such an architecture that will meet these requirements is challenging due to several issues: (a) supporting scalability, (b) meeting computational constraints, and (c) enhancing adapted content quality.

In this chapter, we present the literature of the content adaptation field. The research field of content adaptation have been growing rapidly during the past ten years and this has resulted in a plethora of new concepts, models and systems. An abstract architecture for a content adaptation system that succinctly captures the essential components and functions of a content adaptation system is presented. The significance of the different components and functions of the model are also discussed. A taxonomy that classifies the approaches that form the design space and implementation requirements of content adaptation systems is presented. The applicability of the taxonomy is demonstrated by mapping representative existing systems. Also, this taxonomy is used to perform "gap analysis" by revealing some of the areas that are yet to be fully explored that can lead to creative solutions.

2.2 Background

In this section, we present a generic content adaptation architecture that outlines the different components of content adaptation system architecture. The architecture is important to provide a central knowledge regarding the architecture (i.e., components, functions) choices made by existing content adaptation systems. To keep the model compact, only the core functions of the content adaptation systems are included. The essential definitions for content adaptation are also presented.
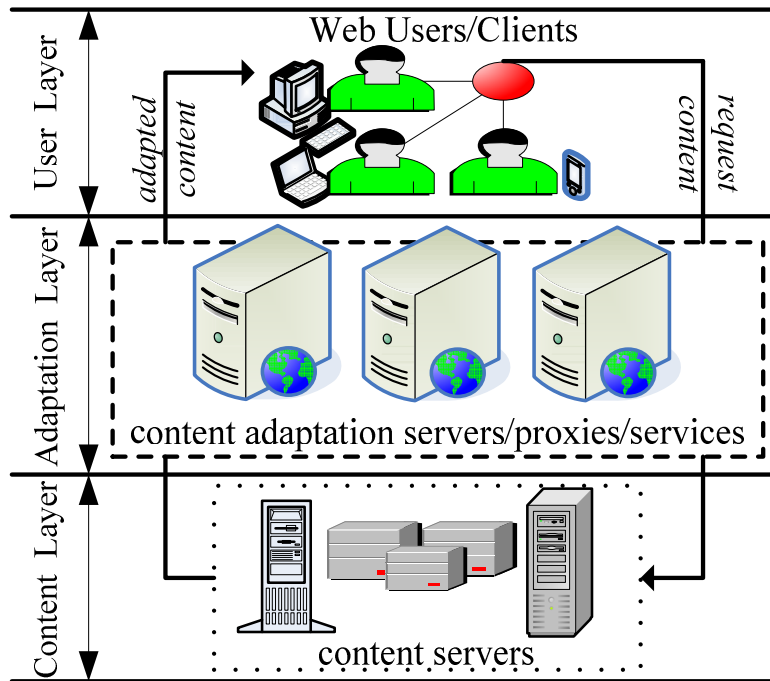
Figure 2.1: Typical content adaptation framework.

Figure 2.1 shows the outline of content adaptation extracted from [2, 6, 13, 19, 20]. Generally, a typical content adaptation contains three layers: user, adaptation and content layers. At the user layer, user/client requests for the Web content from content servers via different devices. The content servers are grouped at the content layer and located in many places across the network. At adaptation layer, original Web content is tailored to meet the contexts (e.g., device's constraints, preferences) of each targeted user determined by adaptation decision. This tailoring process can be performed by the adaptation mechanism(s) at a single or several different locations (e.g., content servers, proxies). Finally, the adapted version of the Web content is delivered to the users.

In content adaptation, several essential terms are defined as the following:

Content adaptation is a term that defines the tailoring, aligning or customizing content into a required version [2, 6]. It is performed to tailor with the adaptation contexts.

Context is the circumstances surrounding an entity or event [21]. This includes any information that can characterize an entity's situation or state.

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Context is motivated by this key question: "to adapt the content to what". It could be a device, network, user/client or combination of them.

Client is a Web user that consumed content adaptation services to get the required content version [12]. Clients use these services directly or through a service broker.

A system must exist with the appropriate logic to analyse the content with all aspects of the contexts and formulate the content adaptation strategy that will deliver a version required by the client. Clients can benefit from the expansion of cross-media adaptation strategies (e.g., media conversion, translation, summarization and integration) provided by third-party service providers. This opportunity has attracted both academic and business communities (e.g., Web services) [15].

In general, a content adaptation system is made of several core components. Some additional components are required for decentralized/distributed architecture. Figure 2.2 shows an abstract model of a content adaptation system. This model is developed by considering existing systems surveyed. The model contains four components and divided into two major blocks: common components and distributed components. Each component has specific function. The abstract model complies with the work presented in [22, 23, 24].

The common block contains two key components: contexts gathering and adaptation decision-taking engine (ADTE). Contexts gathering function is to collect necessary data/information (e.g., network profile, device profile, user preferences) including the content metadata from the particular entity to be considered for adaptation and mapping them into the semantic representation. The content metadata (e.g., Web structure, page dimension, number of objects, links) is collected from the content server. This metadata is produced in a process called content parser [24]. Network profile (e.g., UMTS/GPRS/GSM Data) is gathered on-demand as it is hard to determine the user network environment in advance and can be gathered using a particular network monitoring tool. Client profile (i.e., device profile and user preferences) could be fetched from independent client registry. This registry can be maintained at client profile server and is updated periodically. For instance, client profile can be represented according to the composite capabilities/preference profile (CC/PP) specification

introduced by World Wide Web Consortium (W3C). This profile can be detected through Bluetooth or ZigBee configuration, if activated. Another important function in the context gathering component is contexts (including resources) monitoring [25]. In fact, to ensure content adaptation can be carried out accordingly, context monitoring needs to be measured accurately and efficiently.
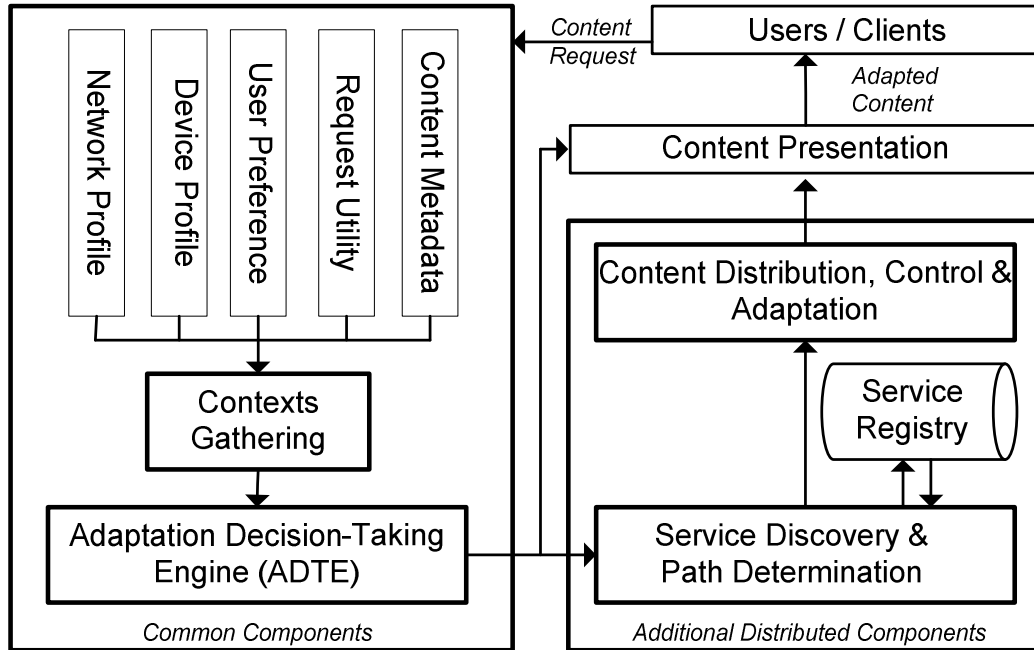
Figure 2.2: Content adaptation abstract model.

These contexts are sent to ADTE for processing. ADTE analyses these contexts with the content metadata to produce adaptation decision for obtaining the required content version. This decision determines the content adaptation tasks/strategies. Example of the decision from ADTE is adaptation information (e.g., media modality value, media fidelity value, number of column, etc). For centralized content adaptation systems, this decision is use by the local adaptation engine to adapt the content accordingly. That is, the ADTE and the adaptation engine is combined as one component and located at the same location. Meanwhile, for distributed content adaptation, the adaptation tasks are distributed to several adaptation proxies across the Internet [13, 14, 15]. Currently, there are three kinds of ADTE model: probability-based model, rule-based model and optimization-based model.

The second block contains two key components for distributed architecture: path determination that includes service discovery and content distribution management. The primary objective of the path determination component is to decide who should perform the adaptation tasks. Establishing content adaptation as a service allows the use of a large number of adaptation mechanisms located in many places in the network thus, a task can be performed by multiple services. To benefit form these services, clients must be able to locate them in the network. This makes service discovery an important component. An efficient service discovery mechanism is essential for the success of the distributed content adaptation systems [26]. Also, selecting appropriate services among the many located services is necessary to increase the overall performance of the system [13].

Content distribution management is required to manage the distribution of content, adaptation tasks (including control information) between clients, local proxy/broker and adaptation service proxies. Via this component, adaptation tasks together with the content segments are distributed to several services to be adapted and a proper control mechanism is imposed to ensure each segment is adapted accordingly. Efficient and secure content distribution between cooperative intermediaries has been discussed in [27]. A content distribution mechanism differs for a content delivery system such as [28] in which the former requires content to be modified by the service proxies along the path. On the other hand, content delivery only deal to provide client with the original content requested from the origin content server through replicated servers across the Internet. A fault tolerance mechanism can assist content distribution to recover failed service(s) [1].

Content distribution can be managed using two approaches: centralized (star-based topology) and decentralized (mesh-based topology). In centralized approach, the service providers must communicate through the local proxy or broker to get and/or to deliver content, while decentralized approach allows direct communication between service providers. As a result, centralized approach suffers additional overhead while decentralized approach requires efficient distribution monitoring. Studies in [29, 1] prove that the decentralized approach performs substantially better than centralized in distributed content adaptation.

2.3 Existing Content Adaptation Systems

In this section, we will provide some descriptions of the existing content adaptation system ranging from the late 90's to the recent years. The example systems surveyed are not exhaustive, but comprehensive enough to cover many of the classes in our taxonomy.

2.3.1 Representative Content Adaptation Systems

The surveyed systems include both centralized and decentralized such as InfoPyramid, Power Browser, PDCAS, VTP, XAdaptor, PACER, ADAPT[2], DCAF, CAF, SCAP, CAIN and PUMA. In the following, we provide some description of each system.

InfoPyramid - InfoPyramid [2] is a centralized proxy-based browsing adaptation system that adapts multimedia Web documents to optimally match the targeted device. It is structured into two components: a multimodal content representation and a customizer that selects the best content representation to tailor device context based on the optimization strategy. In the first component, the content items on a Web page are transcoded into multiple resolution and modality version, before actually analysing the targeted device – static adaptation is implemented. The proxy is responsible for the context monitoring. Appearance, size and format are the supported adaptation strategies.

Power Browser - Power Browser [30] is a centralized proxy-based browsing adaptation system that adapts text display to suit mobile devices. The adaptation contexts are the device and user preference, and being monitored by the proxy. It breaks the Web page into text units that can be easily displayed, hidden or summarized. Each text unit is represented by a keyword. For mobile screen, Power Browser displays this keyword list rather than the whole text units. The full text unit will be displayed if clicked by the user. Four main components are form processor, keyword extractor, sentence ranking and summary generator. Device context is fetched from the profile database. Navigational, appearance and encapsulation are the supported adaptation strategies.

PDCAS - PDCAS [6, 31] enables documents adaptation based on five quality domains: color, downloading time, scaling, modality and segment. These domains correspond to the user input collected in pre-processing phase. This information, together with

contexts gathered in real time, is used in score node selection algorithm to produce desired content. The ADTE adopts optimization strategy. Device, network and user preferences are the contexts monitored by the proxy. It is a dynamic media adaptation system that adopted proxy-based architecture. Appearance, size and format are the supported adaptation strategies.

VTP - Versatile transcoding proxy (VTP) [9] is a centralized proxy-based browsing adaptation system that can accept and execute transcoding preference script provided by the client to transform the corresponding content accordingly. That is, it can deal with multimedia content as long as the transcoding preference is supplied. In addition, a specific transcoding scheme is used to maintain cache objects and perform cache replacement. The adaptation contexts are device and user preferences, which are monitored by the proxy or a service agent. Weighted transcoding graph is used to dynamically select the suitable version. Appearance, size and format are the supported adaptation strategies.

XAdaptor - XAdaptor [8] is an extensible proxy-based browsing adaptation system that classifies page objects into structure, content and pointers objects. The key idea is to adapt based on structure object HTML table. Rule-based strategy is adopted for the ADTE and to provide extensibility. Device and user preferences are the contexts monitored by the proxy. Appearance, size and format are the supported adaptation strategies.

PACER - PACER [32, 33] adapts online educational resources to suit the targeted user with different learning style: personalization. In addition, PACER takes into account not just the interests, but also the current knowledge and goals of their users. This is a dynamic server-based system that can provide adaptive navigation support for browsing-based access to open corpus resources and support information access through adaptive information visualization. The context is monitored by the proxy. The ADTE applies a rule-based strategy. Appearance and navigation are the supported adaptation strategies.

ADAPT[2] - A similar content adaptation system to PACER is ADAPT[2]. The exceptional is the architecture design. It is aimed at providing personalization and adaptation services for developers of otherwise not personalized content [35]. The system's components (e.g., user modelling server, ontology server, value-added service and content server) are designed using distributed architecture. Appearance and navigation are the supported adaptation strategies.

DCAF - Distributed content adaptation framework (DCAF) presented in [1, 5] is a service-oriented media adaptation. It enables adaptation tasks to be performed by a third party. In this system, content adaptation is performed in several steps. The ADTE is not specifically discussed. The path determination is performed using a greedy single objective assignment function. The path associated with highest score is selected as the optimal path. Device, network, user preferences are the contexts monitored by the local proxy. A continuity of this system is ConAMi [35]. It is customized version to support content adaptation for Mobile Ad hoc NETwork (MANET). Size, format, encapsulation, media conversion and translation are the supported adaptation strategies.

CAF - Co-browsing adaptation framework (CAF) presented in [36] is a partially static proxy-based browsing adaptation system. It implements rule-based strategy to tailor content with the device context. The original content is adapted into co-browsing version in order to support co-browsing activity between devices with different capabilities. It is partially static adaptation because the default co-browsing content is adapted before the device context is monitored by the proxy, but not during the authoring time. Appearance, size and format are the supported adaptation strategies.

SCAP - SCAP is a centralized proxy-based solution [16]. Its primary objective is to provide mobile users with adaptive content without direct user input and to provide value-added content. Value-added content is achieved by creating composite content, i.e., best possible presentation of content to the user's device together with additional content as a result of capitalizing request's information. For instance, if a page containing a movie sound track is requested, SCAP will suggest and cross-sell other related products such as video clips and movie trailers. SCAP captures each device

capability (i.e., screen, display and supported media format) from available device capability server. Its ADTE renders a content version suitable to be presented at requesting device by analysing the content metadata to match the device capability. It integrates value added content by performing any of these three methods: content-to-content correlation, attribute-based and collaborative filtering. This value-added content will be presented tailored to each requesting device as well.

CAIN - In this system [37, 38], the content adaptation manager provides meta-data driven content adaptation. It allows multiple content adaptation tools (termed as CATs) to be added in the system. The primary operation of CAIN is to increase user's experience in browsing content by analysing user's context (i.e., terminal capabilities and network characteristic) with the content. CAIN collects the descriptions of both content and user's context. Enabling the addition of new CATs enables a wide range of content adaptation strategies such as transcoding, summation and transmoding. Content and user's context are described using MPEG-7 MDS/MPEG-21 BSD and MPEG-21 DIA, respectively. These inputs are sent to the decision module to decide which CAT is required to provide the best adapted content. CAIN is a centralized proxy based model. The ADTE treated content adaptation as content satisfaction problem by searching for CAT that matched more constraints and the best option. It also provides an optimization method to select the best CAT if more than one available by specifically compare each constraint.

PUMA - It is a service-oriented system that distributes content adaptation to several services along the network before the final adapted content reach the user [14, 39]. It is made of four components: workflow preparation, validation, instantiation and monitoring. Workflow outlines the adaptation steps in sequences; validation component validate the interoperability of the services; instantiation component invoked the services; and monitoring component monitoring the service execution and replaces failing service(s). PUMA's decision engine gets the request with the content preferences and technical constraints through MPEG-21 DIA. It uses Pareto Preference Graph to choose the optimal adaptation (the first option is the best possible option) in a manner similar to constraints satisfaction. PUMA demonstrated that content adaptation under

real-time constraint is possible in a service-oriented way. It has the capability to recover from failures of individual services [40]. PUMA's service discovery and service selection is based on functional aspect and cost offered [41].

In the next subsection, we review some existing taxonomies pertaining to adaptation or content adaptation.

2.3.2 Existing Taxonomies

Content adaptation research area emerged from the idea of bridging the mismatch between requested resources (i.e., content) and the requesting device. Early researches exploited some approaches in solving general adaptation issues. Taxonomies focusing on issues related to adaptation in general are discussed [25, 42]. In [42], adaptation techniques are classified into user-centred, system-centred, and mixed adaptivity. On contrary, [25] classified adaptation techniques into laissez-faire, application-transparent and application-aware. However, both [25] and [42] emphasize on adapting resources, not specifically content per say.

Several taxonomies with specific aspects of content adaptation have been discussed in the literature. An early classification of adaptive hypermedia systems is presented in [22]. However, it only covers basic adaptation strategies that deal with layout rearrangement. Moreover, it does not consider different adaptation contexts such as device and network heterogeneity.

A taxonomy that is specifically dedicated to mobile application is discussed in [43]. Another taxonomy focusing on locality of content adaptation is presented in [5]. The taxonomy breaks content adaptation locality into two groups: centralized and decentralized. Also, a taxonomy that solely focuses on content delivery network (CDN) is presented in [28]. A recent taxonomy in [44] explores QoS issues in customizing content.

As research on content adaptation is quite extensive and the landscape is changing fast, new research issues have been raised. However, the established taxonomies no longer include many of the recent new concepts and developments. Unlike these taxonomies, we present a taxonomy that focuses on design themes and the implementation details of the recent content adaptation systems. This taxonomy is presented in the next section.

2.4 A Taxonomy of Content Adaptation Systems

In this section, the taxonomy of content adaptation is presented. The taxonomy classifies content adaptation by characterizing different components. The intent of the different components and functions is to differentiate content adaptation implementations.

2.4.1 Design Themes

The design objectives for content adaptation motivate the architecture of the content adaptation application. It is important for the application designer to identify the underlying components of content adaptation architecture. We classify the design objectives into two themes: (a) enhancing user's browsing experience and (b) enhancing scalability and media adaptability. Using these themes, content adaptation systems are placed into two categories as shown in figure 2.3.

```
                                                  ┌─── Client-side
                              Browsing             │
                              adaptation ──────────┼─── Content server
Content Adaptation ──┬──────                       │
Design Themes        │                             └─── Proxy
                     │
                     └──────  Media                ┌─── Application-specific
                              adaptation ──────────┤
                                                   └─── Cross-media
```
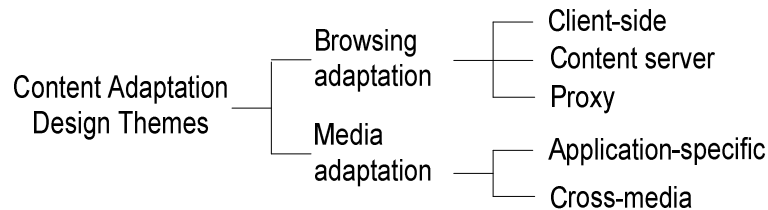
Figure 2.3: Content adaptation design themes taxonomy.

Before the design themes are elaborated, we discuss two different ways on how different content versions can be prepared. One way is by creating and maintaining different format of the original content suitable for the targeted access devices. This approach is used in InfoPyramid [2]. In this case, content is formatted differently for displays that have different capabilities, and is also delivered differently for devices that have a different connectivity [3]. Although the pre-adapted version (i.e., static adaptation) is simple to implement, it suffers from a number of serious drawbacks. To create a pre-adapted content version, a human designer can be involved to hand-tailor a version for some specific rendering requirement [3]. Keeping multiple copies of the original content will lead to tremendous overhead and places unwieldy burden on to the content authors. Moreover, any changes in the content may require changes on every version of the contents, which renders this approach error-prone. In addition, new

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device may require a new format. Clearly, this is neither practical nor feasible for providers of large volumes of content.

An alternative content adaptation approach is to automatically generate any content version from one single original version such that the content is adapted to the device and the user preferences (i.e., dynamic adaptation). This requires a content adaptation system with the appropriate logic to analyse the content and all aspects of the delivery context and formulate the content adaptation strategy that will deliver the required content version. Dynamic adaptation provides suitable adapted version to each device or client and no multiple versions is created at the authoring time. [3, 6, 7, 8, 9, 10, 16] are some examples of content adaptation systems performing dynamic adaptation.

2.4.1.1 Browsing Adaptation

The browsing adaptation (also known as general purpose) category denotes systems that focus on adapting content to enhance user's browsing experience. It concerns with tailoring Web properties (e.g., layout, table, text column) and objects properties (e.g., size, format) to the diversity and heterogeneity of users devices. Most of the earlier systems such as InfoPyramid [2], Power Browser [30], and Odyssey [45] belong to this category. These systems can further be subdivided into client-side and server-side adaptation approaches.

In client-side approach, the client itself (e.g., netbook, PDA, smart phone) needs to perform the adaptation, and then send the adapted Web to the user's display. For example, after downloading the Web page requested by the user, the adaptation is performed to suit device's capabilities at the client, immediately before the adapted page viewed by the user. [36] is one of the example that used this approach. The main advantage of this approach is that the device capabilities can be determined directly. However, some requirements (at client side) of the adaptation (such as processing, encoder) may not be available and insufficient.

In server-side approach, adaptation is performed at the origin server, where the original Web page resides. For example, while the user requests to browse a particular Web content, the server automatically collects the related contexts (device's profile, user preferences, and network constraints) and adapts accordingly. [45, 46] are among the pioneer systems designed with this approach in mind. Server-side approach

performs very well for relatively small number of users, but will suffer overload if too many simultaneous requests.

Alternatively, content adaptation can be performed by a middleware i.e., proxy-based approach. [2, 8, 9] are some browsing adaptation systems that implemented this approach. Content adaptation and contexts monitoring is managed by external server called proxy. Some of these browsing category systems [2, 30, 45] implement fixed and hard-coded algorithms to easily and securely control the adaptation process, however leads to the difficulty to adapt changes especially when the new browsing requirements is introduced. More recent projects such as VTP [9] and Xadaptor [8] used scripts and agents to facilitate the server with extensibility and flexibility capabilities.

2.4.1.2 Media Adaptation

The media adaptation category is for systems that provide specific media adaptation. This category is further subdivided as application-specific and cross-media. Application-specific proxy is designed to handle a specific media adaptation. For instance, an image type adaptation proxy only caters image adaptation. In application-specific, adaptation is managed by varying fidelity; the qualities or formats of the specific media. For example, an image may have different colour scheme, format or size. The adaptation engine computes for the best version to suit the contexts. One example system is Portable Document Format Content Adaptation System-PDCAS [6, 31]. It tailors portable document format into suitable version (e.g., WBMP, WML or PDF, with 2, 16 or 256 colours) based on user preferences, device profiles and network environment.

On the other hand, cross-media is performed by transforming one media type into another [47]. For instance, the video data can be transformed into a series of images. Also, we can convert text into audio file to assist users to read text message or important email while driving.

2.4.2 Content Adaptation Strategies

Both browsing adaptation and media adaptation have to perform a particular strategy(s) to provide the user with the required content version. Specifically, content adaptation strategies are important to classify the action required to adapt the content according to the contexts. This organization differentiates the different action towards tailoring the

content to the targeted contexts. It answers the question "how to adapt the content". As shown in figure 2.4, content can be adapted using several strategies: size adaptation, appearance adaptation, format adaptation, encapsulation adaptation, summarization, translation, media conversation and navigational adaptation.

```
                              ┌───── Appearance adaptation
                              ├───── Size adaptation
        Content              ├───── Format adaptation
        Adaptation  ─────────┤───── Encapsulation adaptation
        Strategies           ├───── Media conversion
                              ├───── Translation
                              └───── Navigational adaptation
```
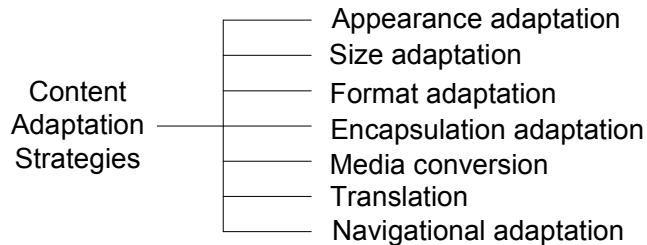
Figure 2.4: Content adaptation strategies taxonomy.

Most of the new Web sites designed with a fixed width and have a centred column where the main text resides. To read overall text, user needs to scroll horizontally and vertically. One way to deal with this is through the appearance adaptation. A real life example of appearance adaptation is the Opera's Small Screen Rendering™ technology [48]. Basically, in this strategy, only the Web layout is adjusted while preserving the content and functionality. In [10], a multi column Web is altered into a single column while preserving the content. Both examples eliminate horizontal scrolling.

Web authors often include objects such as images and video to attract users. Those objects' sizes are relatively normal for desktop viewing. But for mobile display, this is intolerable. This requires size adaptation and can be done by resizing or scaling the object's dimension. [49] proposed an attention model to adapt the image according to the particular display's size.

A media can be represented by different format. For instance, an image can be displayed using different colour scheme (black & white, 2-bits) and different format (e.g., jpeg, bitmap). Format adaptation is performed by changing incompatible content into a more suitable format in the same media. It is widely use in the area of mobile application, due to the devices diversity. For instance, considers Multimedia Messaging Service (MMS) communication over the network. Today embedded phone's camera usually provides user with high quality image. During delivery, this higher quality image should be transcoded to a lower resolution image with fewer colours in order to

better fit the targeted device. In [6, 31], the most suitable document format is generated to suit the targeted device. For example, a HTML document will be transformed to a compact format version (cHTML) that more suitable for small screen.

When a user looks for shorter version of the original content, summarization adaptation can be used. The key idea is to extract the most important aspect of the content that enough to convey the overall content. This practice is similar to executive summary in an annual report, which allows reader to grasp the gist. Through this strategy, [46] proposed Unit of Information concept to represent the Web content structure. It compromises of a set of segments and media objects to be presented together. When summarization is required, the most important content set is selected. In [30], an approach that breaks each web page into text units that can easily be displayed, hidden, visible or summarized, is presented, while [50] proposed a block-based content decomposition structure, where a HTML page is factorized into blocks with assigned scoring value. Content block with the highest score will be displayed. For a Web with a long text, instead of changing the column layout, the text itself also can be adapted by summarizing it into a shorter version.

Media conversion is concerned with adapting one content media from one type into another. It is more complicated if compared to other strategies. It can be done by converting or transforming the media type. For instance, if a client device cannot support video content, it can be transformed into a series of images. This enables some information to be conveyed to the user. Media-Convert [51] is an online service that enables audio visual media file to be converted, separated and integrated.

When dealing with language barrier, translation adaptation can be implemented. For instance, a user could request for a specific English audio file. However, only the Spanish version is currently available. Using translation, the Spanish audio can be converted into English audio. WebServiceX.Net [52] is an example of Web Services that provide language translation service.

Navigational adaptation strategy is used to guide user to access content based on their knowledge and interest. That is content is tailored to provide the user with content keyword(s) rather than the whole content segment. When the keyword is clicked, it will navigate the user to the desired content. [30, 32, 33, 34] are the examples of systems implemented this strategy.

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