Web Engineering: A New Discipline for Development of Web-Based Systems

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Abstract. In most cases, development of Web-based systems has been ad hoc, lacking systematic approach, and quality control and assurance procedures. Hence, there is now legitimate and growing concern about the manner in which Web-based systems are developed and their quality and integrity. Web Engineering, an emerging new discipline, advocates a process and a systematic approach to development of high quality Web-based systems. It *promotes the* establishment and use of sound scientific, engineering and management principles, and disciplined and systematic approaches to development, deployment and maintenance of Web-based systems. This paper gives an introductory overview on Web Engineering. It presents the principles and roles of Web Engineering, assesses the similarities and differences between development of traditional software and Web-based systems, and identifies key Web engineering activities. It also highlights the prospects of Web engineering and the areas that need further study.

Keywords: Web engineering, Web-based systems development, Web crisis, Web design, Web development, Web lifecycle

1 Introduction

The growth of the Internet, Intranets, Extranets, and the World Wide Web has had significant impact on business, commerce, industry, banking and finance, education, government and entertainment sectors, and our personal and working lives. Many legacy information and database systems are being migrated to Internet and Web environments. Electronic commerce through the Internet is rapidly growing, cutting across national boundaries. A wide range of new, complex distributed applications is emerging in the Web environment because of the popularity and ubiquity of the Web itself and the nature of its features: it provides an information representation that supports interlinking of all kinds of content, easy access for end-users, and easy content creation using widely available tools.

In most cases, however, the development approach used for Web-based systems has been ad hoc, and many Web-based systems have been kept running through a continual stream of patches. Overall, Web-based systems development has lacked rigour, systematic approach, and quality control and assurance. As the complexity

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and sophistication of Web-based applications grow, there is now legitimate and growing concern about the manner in which they are created and their quality and integrity.

In the absence of disciplined process for developing Web-based systems, we may face serious problems in successful development, deployment, operation and 'maintenance' of these systems. Poorly developed Web-based applications that are escalating now have a high probability of failure. Worse, as Web-based systems grow more complex, a failure in one system or function can and will propagate broad-based problems across many systems and/or functions. When this happens, confidence in the Web may be shaken irreparably, which may cause a Web crisis [1]. The potential Web crisis could be more serious and widespread than the software crisis, which the software developers have been facing [2].

In order to avoid a possible Web crisis and achieve greater success in development and applications of complex Web-based systems, there is a pressing need for disciplined approaches and new methods and tools for development, deployment and evaluation of Web-based systems. Such approaches and techniques must take into account: 1) the unique features of the Web, 2) operational environments of Web-based systems, 3) scenarios and multiplicity of user profiles, and 4) diverse type (and skills and knowledge) of the people involved in building Web-based systems. These pose additional challenges to Web-based application development.

Motivated by the concern among some Web-based systems developers (including the authors) about the chaotic way in which most Web-based systems are developed, a few new initiatives were undertaken to address the problems of Web-based systems development and bring the potential chaos under control, and to facilitate successful Web-based systems development [3-7]. These initiatives have promoted Web engineering as a discipline.

Web Engineering is concerned with establishment and use of sound scientific, engineering and management principles and disciplined and systematic approaches to the successful development, deployment and maintenance of high quality Web-based systems and applications.

It incorporates some of the well-known and successful traditional software ‘engineering’ principles and practices, adopting them to more open and flexible nature of the Web, and the type of Web application. It also takes into consideration other elements that are specific to the Web environment.

We organised the first workshop on Web Engineering in 1998 [3] in conjunction the World Wide Web Conference (WWW7) in Brisbane, Australia, to address the state of Web-based systems development and to promote Web engineering approaches. Building on the success and outcome of the first workshop [3], two more workshops on Web engineering were organised in 1999 [5, 6] to review practices in Web-based systems development and the progress in this area, and to pave directions for further study. The *IEEE Software* magazine [4] presented an interesting roundtable discussion on “Can Internet-Based Applications be Engineered?” Also a few Web engineering related articles [7-14] were published. These invoked a growing interest in Web Engineering - a new discipline and approach for successful Web-based systems development.

This paper gives an introductory overview on Web Engineering in order to promote this new discipline among Web-based systems developers, researchers, academics and students.

The paper assesses the problems of Web-based systems development as is currently practiced and argues the need for adopting Web Engineering approaches for developing scalable, quality, large-scale Web-based systems. It outlines the principles and roles of Web Engineering and also assesses the similarities and differences between development of traditional software and Web-based systems, and between software engineering and Web engineering. The paper consequently identifies key Web engineering activities and highlights approaches and methods for systematic development of Web-based applications reviewing ongoing work in this area. Finally, the paper discusses the prospects of Web engineering and highlights the areas that need further study and development.

[For an updated list of some useful resources, such books, articles, workshop proceedings and Web sites, on Web engineering see pages 363-365].

2 Ad Hoc Approaches and Concerns

The Web has evolved very rapidly into a global environment for delivering all kinds of applications, ranging from small-scale, short-lived services to large-scale enterprise applications widely distributed across the Internet and corporate intranets. Tracking the Internet's global diffusion [15], and its influences and impact on society at large is a daunting task, perhaps an impossible task. According to an estimate [15], commercial use accounts for 58% of Internet traffic, far exceeding the networks' originally intended application in defense and research and development [16].

Development approaches used for Web-based systems have been ad hoc [3-14,17]. Hardly any attention was given to development methodologies, measurement and evaluation techniques, application quality and project management. Further, most current applications development and management practices heavily rely on the knowledge and experience of individual developers and their own development practices. In addition, they lack proper testing of Web-based systems, and documentation which is needed for 'maintenance and upgrade' of the systems among other needs.

Problems of Web-based systems development can partly be attributed to the nature and rapid growth and evolution of the Web, the boom in Web and Web-related technologies, the commercialisation of the Web, the rush to "be on the Web" and the desire (or need) to migrate the legacy systems to Web environments. Also the complexity of Web-based applications has grown significantly - from information dissemination (consisting of simple text and images to image maps, forms, CGI, applets, scripts and stylesheets) to online transactions, enterprise-wide planning and scheduling systems and Web-based collaborative work environments. The complexity of Web-based systems, however, is generally underestimated.

Web's legacy as an information medium rather than an application medium is another cause of the problem. Many developers, clients and managers, as well as academics still consider Web development primarily as an authoring activity rather than an application development to which some of the well-known software engineering and management principles and practices could apply – of course with some changes and fine tuning to suit to the Web environment. Web-based systems development is a process – "it is more than media manipulation and presentation creations - it includes analysis of needs, design, management, metrics, maintenance, etc [11]".

Many attributes of quality Web-based systems such as ease of navigation, accessibility, scalability, maintainability, usability, compatibility and interoperability, security, readability, and reliability are often not given due consideration during development. Many developers seem to be unaware of the real issues and challenges facing major Web-based application development and its continual maintenance.

There is now legitimate and growing concern about the ad hoc manner in which most Web-based systems are currently created and their long-term quality and integrity. Further, more sophistication and increased complexity of some Web-based applications bring in many new challenges that need to be satisfactorily addressed.

To address these concerns and challenges, first we need to create an awareness of the need for more disciplined approaches to Web-based application development and also move from the current, largely ad hoc (and personalised) approach to a disciplined approach and process. Importantly, we also need to realise that Web-based systems development is not just graphic design or content development any more; there are growing number of complex applications – intranet-based applications, transactional systems, and other e-business applications. "There is more to Web site than visual design and user interface. Web sites are becoming more like programmes, less like static documents" [9]. Hence Web-based systems developments are becoming more like major [software/IT] projects, and less like work of art.

3 Web Engineering: The Need and Principles

In the absence of a disciplined approach to Web-based systems development, we will find sooner or later that:

a) Web-based applications are not delivering desired performance and quality.
b) Web application development process becomes increasingly complex and difficult to manage and refine and also expensive and grossly behind schedule.

Web Engineering, an emerging new discipline, advocates a process and a systematic approach to development of high quality Internet- and Web-based systems. We provide a broad and objective definition of Web engineering as follows.

Web engineering is the establishment and use of sound scientific, engineering and management principles and disciplined and systematic approaches to the successful development, deployment and maintenance of high quality Web-based systems and applications.

Web engineering principles and approaches can bring the potential chaos in Web-based systems development under control, minimise risks, and enhance maintainability and quality.

3.1 Web Engineering and Gardening Metaphor

Many Web-based systems call for continual update or refinement, and hence Web-based systems development may be considered "continuous, with fine grained evolution, without specific releases as with software." Thus, Web-based systems development is like gardening [8, 18]. Like a garden, a Web-based system will continue to evolve, change and grow. Hence, a good initial infrastructure is required

to allow the growth to occur in a controlled, but flexible and consistent manner, and to foster creativity, refinement and change.

The gardening metaphor for Web application development raises the question about the appropriateness of engineering approach. We believe Web engineering is appropriate for Web application development, and, in support of this view, cite the relationship between horticultural engineering and gardening. Engineering principles and approaches can be adapted to Web environment to provide required flexibility to work within a framework and allow creative development. They are not as 'rigid' as perceived by some based on their perception of 'traditional engineering' approaches, and allow creativity and personalisation to blossom within a framework. In fact, all that Web engineering advocates is "use of sound scientific, engineering and management principles and disciplined and systematic approaches to the successful development, deployment and maintenance of high quality Web-based systems and applications."

3.2 Web Engineering and Software Engineering

Though Web engineering involves some programming and software development, and adopts some of the principles of the software engineering, Web-based systems development is different from software development, and also Web engineering is different from software engineering.

1. Most Web-based systems, at least as of now, are document-oriented containing static or dynamic Web pages.
2. Web-based systems will continue to be focussed on look and feel, favouring visual creativity and incorporation of multimedia (in varying degrees) in presentation and interface. More emphasis will be placed on visual creativity and presentation in front-end user interfaces.
3. Most Web-based systems will continue to be content-driven; often Web-based systems development includes development of the content presented.
4. Most Web-based systems need to cater to users with diverse skills and capability, complicating human-computer interaction, user interface and information presentation to a multiplicity of user profiles.
5. The nature and characteristics of the Web as an application medium as well as a delivery medium is not yet well understood.
6. The Web exemplifies a greater bond between art and science than generally encountered in software development.
7. Most Web-based systems need to be developed within a short time, making it difficult to apply the same level of formal planning and testing as used in software development.
8. Web is different from software as related to the delivery medium. Traditional software generally operates in a well-defined environment whereas the Web-based systems, at the user end, have to cater to diverse environments.
9. The type of individuals who build/develop Web-based systems are vastly varied in their background, skills, knowledge and systems understanding, and as well as their perception of Web and quality Web-based system.

3.3 Web Engineering: A Multidisciplinary Field

As Powell [9] writes, Web-based systems "involve a mixture between print publishing and software development, between marketing and computing, between internal communications and external relations, and between art and technology."

Because of the nature and characteristics of Web-based applications and their development, Web engineering needs to be a multidisciplinary field, encompassing inputs from diverse areas such as human-computer interaction, user interface, systems analysis and design, software engineering, requirements engineering, hypermedia engineering, information structures, testing, modeling and simulation and project management, as well as social sciences, arts and graphic design (Figure 1).

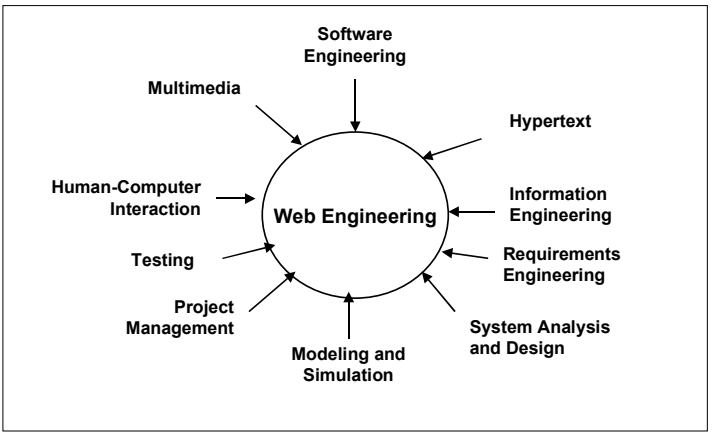

Figure 1. Web Engineering – a multidisciplinary field

3.4 Web Engineering Activities

Web development is a process, not simply a one-off event. Thus, Web Engineering deals with all aspects of Web-based systems development, starting from conception and development to implementation, performance evaluation, and continual maintenance.

Major Web Engineering activities include:

- Requirements specification and analysis
- Web-based systems development methodologies and techniques
- Migration of legacy systems to Web environments
- Web-based real-time applications development
- Testing, verification and validation
- Quality assessment, control and assurance
- Configuration and project management
- "Web metrics" - generating metrics for estimation of development efforts
- Performance specification and evaluation
- Update and maintenance
- Development models, teams, staffing
- Integration with legacy systems

- Human and cultural aspects
- User-centric development, user modeling and user involvement and feedback
- End-user application development
- Education and training

4 Web-Based Systems Development

While Web engineering activities span the entire Web lifecycle from conception of an application to development and deployment, and continual refinement and update/upgrade systems, in the following we highlight some of the [early] developments in this area, presented in this volume as well as elsewhere. This is, however, not intended to be an extensive survey or critical review of these developments.

4.1 Web Development Process Models

To better mange Web-based systems design and development, and to do it in a systematic and repeatable manner, we need a process that outlines the various phases of Web-based systems development. Some aspects that make Web-systems development difficult include complexity, changeability, invisibility and unrealistic, narrow schedules [10]. A process model should help developers "to address the complexities of Web-based systems, minimise risks of development, deal with likelihood of change, and deliver the site quickly, while providing feedback for management as the project goes along" [10]. Further, the progress of Web-based development should be monitorable and trackable. The process besides being easy to apply should facilitate continual update/refinement and evolution, based on feedback from users/clients. For information on some of the hypermedia/Web development process models see [9-14]. An object-oriented model for the Web application development process, which uses XML technology to support modularity and reuse of Web document, is described in [19].

4.2 Analysis and Web Design

Requirement analysis and Web-based systems design are very important activities and call for a systematic and disciplined approach. Web systems design considerations and approaches are discussed in [9, 20-23].

Object Orientation in Web-Based Systems. Integration of Web and object technologies offers foundation for expanding the Web to a new generation of applications. According to Manolo [24], Web must improve its data structuring capabilities, and integrate aspects of object technology with the basic infrastructure of the Web. He argues that if the Web is to support complex enterprise applications, it must support generic capabilities similar to those provided by the OMA (object management architecture), but adapted to the more open, flexible nature of the Web and to the specific requirements of Web applications. Technologies for Web object model are described in [24].

Usability and User-Centered Designs. Effective Web site design requires consideration of usability. Web-based systems need to be designed for easy navigation, and also they need to be attractive and useful [25]. User-centered design methods for Web sites are presented in [26], while [27] presents a user-centric approach to modeling Web information systems.

4.3 Testing of Web-Based Systems

Testing, verification and validation (V & V) of Web-based systems is an important and challenging task. But, it receives very little attention by Web developers. Web-based systems testing differs from conventional software testing and poses new challenges. A Web-based system needs to be tested not only to check and verify whether it does what it is designed to do but also to evaluate how well it performs in (different) Web client environments. Importantly, they need to be tested for security and also for usability from the users' perspective. However, the unpredictability of the Internet and Web medium makes testing of Web based systems difficult. We need to develop new approaches and techniques for testing and evaluation of complex Web-based systems. For a brief overview on Web systems testing see Chapter 8 in [9] and [28–30].

4.4 Management of Large Web Sites

Management of large Web sites is a difficult task, especially in the midst of change, which is a fact of life in the Web environment. Requirements for management of large Web sites, and the tools and a mechanism for organising and manipulating large Web sites are described in [31].

Web Configuration Management. Web-based systems undergo changes, perhaps more often and quite extensively, in their development and operational period. The changes may include trivial to large-scale change of information/data and requirements. These changes need to be handled in a rational, controlled manner. Web configuration management (WCM) encompasses a set of activities for controlling and facilitating change: identification, version control, change control, auditing and reporting. It also provides a framework for handling change in a rational, controlled manner. It could adopt commonly practiced software configuration management (SCM) concepts, principles and approaches to the Web environment. Dart [32] discusses how software configuration management techniques and practices could be used for WCM and to contain the Web Crisis.

4.5 Skills Hierarchy

Large Web-based systems development requires a team of people with different skills, knowledge and capabilities. A categorisation of skills and knowledge-base hierarchy for participants in Web-based systems development is provided in [33] and also in this volume (pp 228-241).

4.6 Barriers to Web Technology Adoption

Nambisan and Wang [34] identify three levels of adoption of Web technology - Level 1: information access, level 2: work collaboration, and Level 3: core business transaction. They also identify three key areas of potential knowledge barriers to Web technology adoption: technology-related knowledge barriers, project related knowledge barriers, application related knowledge barriers.

5 Areas of Further Study

Web engineering discipline is very young and has just started gaining attention of researchers, developers, academics, and other major players in Web-based systems implementation such as customers/clients and their contract administrators. It needs to evolve and mature to effectively handle the new, unique challenges posed by Web-based systems and applications. We need to study and evaluate current approaches and practices, and develop new methods and techniques to address the challenges of developing large-scale Web-based systems. The areas that need further study include (not in any specific order):

- Requirement analysis and systems design
- Information modeling
- Process and product models
- Testing, verification and validation
- Performance measures
- Web metrics
- Configuration and project management
- User interface, ease of use
- User-centric design, end-user development/personalisation
- Quality control and assurance
- Education and training

6 Prospects of Web Engineering

As we improve our ability to build Web-based systems, the systems we need to build are likely to get more complex. The quality requirements and features of these systems may also change with more emphasis on performance, correctness and availability of Web-based systems, as we will increasingly depend on Web-based systems in a number of critical applications, where the consequences and impact of errors and failures could be serious. Further, as systems become larger, a large team of developers with different types and levels of skills would be required, necessitating distributed collaborative development. As we move further in cyberspace and try to exploit some of the unrealised potentials of the Internet and Web, there will be many new challenges and problems. Hopefully, new approaches and directions would be developed to meet the challenges and solve the problems we may face on our mission to build a better cyberspace for us.

Successfully convincing developers of Web applications about the need for and the benefits of Web engineering approaches (which if implemented thoughtfully) will go a long way to reduce the complexity and lead to successful development.

Like the Web, which is dynamic and open, Web engineering needs to evolve rapidly, adapting to the changes, responding to the needs, shifting the emphasis as needed and following new paths.

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