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

San Murugesan, Yogesh Deshpande, Steve Hansen and Athula Ginige
WebISM (Web-based Information Systems and Methodologies) Research Group
Dept of Computing and Information Systems
University of Western Sydney Macarthur
Campbelltown NSW 2560, Australia
{s.murugesan, y.deshpande, s.hansen, a.ginige}@uws.edu.au

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 long-term 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, identifies key Web engineering activities and reviews some of the ongoing work in this area. It also highlights the prospects of Web engineering and the areas that need further study.

Keywords: Web engineering, Web-based system development, Web crisis, Web design, Web development, Web life cycle

1. INTRODUCTION

The growth of the Internet, Intranets, Extranets, and the World Wide Web has already had a significant impact on business, commerce, industry, banking and finance, education, government and entertainment sectors, and our personal and working life. Many legacy information and database systems are being migrated to the Internet and the 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. The popularity and ubiquity stems from the nature of the Web itself and 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.

However, in most cases, the development approach used for Web-based systems has been ad hoc, and Web-based systems have been kept running through a continual stream of patches. Overall, Web-based system development lacks rigour, a systematic approach, and quality control and assurance. As the complexity and sophistication of Web-based applications grow, there is now legitimate and growing concern about the manner in which they are created and their long-term quality and integrity.

In the absence of disciplined process for developing Web-based systems, we may face serious problems in their successful development, deployment, operation of and 'maintenance.' Poorly developed Web-based applications that are mushrooming now have a high probability of failure. Worse, as Web-based systems grow more complex, a failure in one can and will propagate broad-based problems across many. When this happens, confidence in the Web may be shaken irreparably, causing 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. Importantly, such approaches and techniques must take into account 1) the unique features of the new medium, 2) the operational environments, and 3) scenarios and multiplicity of user profiles, as well as 4) the type (and skills and knowledge) of the people building Web-based systems. These pose additional challenges to Web-based application development.

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 and 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.

In the last two years, motivated by the concern among some Web-based system developers (including the authors) about the chaotic way in which most Web-based systems are developed, a few new initiatives have been undertaken to address the problems of Web-based system development and bring the potential chaos under control and to facilitate successful Web-based system development [3-7].

The authors 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 system development and discuss Web engineering approaches. Also, the *IEEE Software* magazine [4] organised an interesting roundtable discussion on "Can Internet-Based Applications be Engineered?" Building on the success and outcome of the first workshop [3], two more workshops on Web engineering have been organised in 1999 [4, 5] to review current practices in Web-based system development and the progress in this area, and to pave directions for further study. Other Web engineering related information can be found in [6-14]. There is a growing interest in the area of Web Engineering - a new discipline and approach to successful Web-based systems development.

The objective of this paper is to give an introductory overview on Web Engineering and to promote the new discipline of Web Engineering among Web-based system developers, researchers, academics and students.

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

2. AD HOC APPROACHES AND CONCERNS

The Web has very rapidly evolved 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, and perhaps an almost an impossible task. According to an early estimate [15], commercial use of the Internet traffic accounts for 58% of Internet traffic, far exceeding the networks' original purpose in research and development [16].

2.1 Disorganised/Tangled Web

In most cases, the development approach used for Web-based systems has been ad hoc, and software development for the Web lacks rigour and a systematic approach [3-14, 17]. Hardly any attention is 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, there is lack of proper testing of Web-

based systems, and documentation which is needed for 'maintenance and upgrade' of the system among other needs.

The nature and rapid growth/evolution of the Web, rapid boom in Web and Web-related technologies, the commercialisation of the Web, and the rush to "be on the Web" and to migrate the legacy systems to Web environments can partly be attributed to problems of Web-based system development. 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, Web-based collaborative work environments, etc. But, the complexity of Web-based systems is often deceptive.

Further, Web's legacy as an information medium rather than an application medium is another cause of the problem. Many consider Web development primarily as an authoring problem rather than an application development problem 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 suite 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 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 a need to engender an awareness of the need for more disciplined approaches to Web-based application development, and we need to move from the current, largely ad hoc (and personalised) approach to a better disciplined approach and process. Also we need to realise that Web-based system development is not just graphic design or content development any more, and 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", and hence Web-based systems developments are becoming more like software projects, and less like work of art.

There is 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. More sophistication and high complexity of new Web-based applications bring in many new challenges that need to be satisfactorily addressed.

3. WEB ENGINEERING: THE NEED AND PRINCIPLES

In the absence of a disciplined approach to Web-based system development, we will find sooner or later that Web-based applications are not delivering desired performance and quality, and that 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 system development under control, minimise risks, and enhance maintainability and quality.

3.1 Web Engineering and Web Gardening

Many Web-based systems call for continual update or refinement, and hence Web-based system development may be considered as "continuous, with fine grained evolution, without specific releases as with software." In this respect, Web-based system development is like gardening [8, 18] – like a garden, Web-based system will continue to evolve, change and grow. However, 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 garden analogy to Web-based system development and the nature of Web as a flexible medium may make us think, or wonder, for a moment whether Web engineering approaches are appropriate for Web-based system development. We believe that they are appropriate, as they are adapted to Web environment and provide flexibility to work within a framework and allow creative development. They are not as 'rigid' as perceived by some based on their perception of some of the 'traditional engineering' approaches, and allows creativity and personalisation to blossom within a framework/limited boundaries. 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." It is appropriate provided we make sure that the approaches are appropriate to the Web environment. Both the Web engineering and Web gardening metaphors are valid in Web environment, and perhaps we may need to follow what is appropriate from both the approaches.

3.2 Web Engineering Logo

The Web engineering logo (Figure 1) depicts the philosophy, objective and goals promoted by Web engineering: a framework and methodology for Web-based system development that supports creativity and flexibility, and still retains and respects the characteristics and the features of the Web medium.

Figure 1. Logo of Web Engineering

The outer square symbolises a broad framework and guidelines for Web-based systems development. The spider web inside the square represents the World Wide Web, and also implies that there is room for creativity, flexibility, and adoption to specific applications. WebE stands for Web Engineering.

3.3 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 system 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 as regards to the front-end interface with which a user interacts.
3. Most Web-based systems will continue to be content-driven – often Web-based systems development include development of the content presented.

4. Multiplicity of user profiles – Most Web-based systems need to cater to users with diverse skills and capability, complicating human-computer interaction, user interface and information presentation.
5. The nature and characteristics of the medium of Web is not well understood as the software medium.
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. Also Web is different from software as related to the delivery medium.
9. Further, the type of individuals who build/develop Web-based systems are vastly varied in their background, skills, knowledge and system understanding, and as well as their perception of Web and quality Web-based system.

3.3 Web Engineering: A Multidisciplinary Field

As Powel [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."

In view of the nature of the Web and Web-based applications, Web engineering is bound to be a multidisciplinary field, with 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 2).

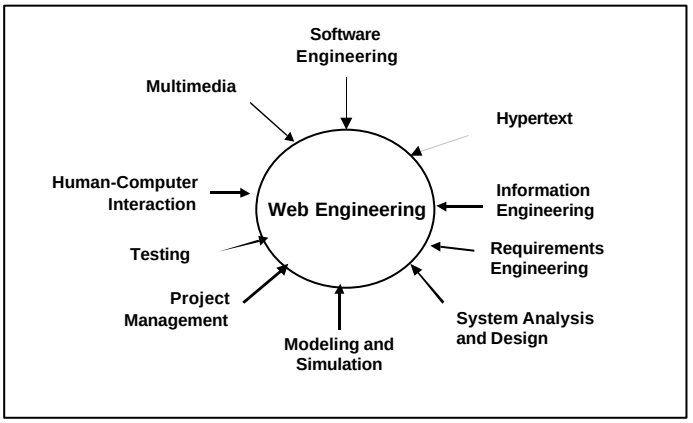

Figure 2. Web Engineering – A multidisciplinary field

3.4 Web Engineering Activities

Web Engineering is not a single activity or task. It deals with all aspects of Web-based system development, starting from conception and development to implementation, performance evaluation, and continual maintenance. Major Web engineering include:

- Requirements specification and analysis
- Web-based system development methodologies and techniques
- Integration with legacy systems
- Migration of legacy system to Web environments
- Web-based real-time applications development
- Testing, verification and validation

- Quality assessment, control and assurance
- Configuration and project management
- "Web metrics" - metrics for estimation of development efforts
- Performance specification and evaluation
- Update and maintenance
- Development models, teams, staffing
- 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

As highlighted in the previous sections, Web engineering activities span the entire Web life cycle from conception of an application to development and deployment, and continual refinement and update/upgrade systems. The following highlights some of the work and development in the area of Web engineering. They are however, not an extensive survey or critical review of the work reported.

4.1 Web Development Process Models

To help to reduce the difficulty in building Web-based systems we need a process model that describe the phases of Web-based system development - some of the aspects that make Web-system difficult include complexity, changeability, invisibility and unrealistic schedule [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 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 system design is a very important activity and calls for a systematic and disciplined approach. Some of the approaches and design considerations are described in [9, 20-23].

Object Orientation in Web-Based Systems. Integration of Web and object technologies offer foundation for expanding the Web to a new generation of applications. According to Frank Manolo [24], Web must improve its data structuring capabilities, and integrate aspects of object technology with the basis infrastructure of the Web. He also 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], and [19] proposes an object-oriented model for the Web application development process.

Usability and User-Centered Designs. Effective Web site design requires attention to 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 is presented in [26], while [27] presents a User-Centric Approach to Modeling Web Information Systems.

4.3 Testing of Web-Based Systems

Testing, and verification and validation (V & V) of Web-based systems is an important and challenging task in the Web engineering process. And, yet very little attention is given by Web developers to testing and evaluation. Web-based system testing differs from conventional software testing and poses new challenges. Web-based systems need 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 appears on (different) Web browsers. Importantly, they need to be tested for security and also for usability, from the ultimate user's perspective. However, the unpredictability of the Internet and Web medium makes testing Web

based systems difficulty. Currently, not much attention is given to Web–based system testing by developers. Also we need to develop new approaches and techniques for testing and evaluation of complex Web-based systems. For a brief overview on Web-based testing see Chapter 8 in [10]. Also see [28–30] for brief notes on Web-based systems/Internet software testing.

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 called for may include trivial to large-scale change of information/data and major modification to requirements, and also may vary in their significance. 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. In [32] Susan Dart 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 system 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 system development is provided in [33].

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. For detail see [34].

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 system 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 system development. 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 system design
- 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
- Information modeling
- 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 dependent 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 people 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 problem, and 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 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, adopting to the changes, responding to the needs, shifting the emphasis as needed and following new paths.

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URLs of Some Useful Online Resources

WebE Home	http://fistserv.macarthur.uws.edu.au/san/WebEhome/
Web Standards	http://www.webstandards.org
W3DT: World Wide Web Design Technique	wwwi-wu-wien.ac.at/w3dt/
Web Architect:	www.nttlabs.com/`kt/webarchitect/
Internet Engineering Task Force	http://www.iete.org
