Characterizing Interactive Web Applications – Findings from an Interdisciplinary Research Project

Kristian Billeskov Bøving
Film and Media Studies
University of Copenhagen
Njalsgade 80
DK-2300 Copenhagen S, Denmark
+45 353 28103
boeving@hum.ku.dk

Sisse Finken, Dixi Henriksen, Jens K. Pors
Computer Science
Roskilde University
Building 42.1 P.O. Box 260
DK-4000 Roskilde, Denmark
+45 4674 3839
[finken, dixi, pors]@ruc.dk

Hanne Westh Nicolajsen
Center for Tele-Information
Technical University of Denmark
Building 371
DK-2800 Lyngby, Denmark
+45 4587 1577
westh@cti.dtu.dk

Lasse Vogelsang
IT University of Copenhagen
Glentevej 67-69
DK-2400 Copenhagen NW, Denmark
+45 3816 8849
vogelsang@it-c.dk

ABSTRACT

In the following work-in-progress paper we discuss a research project investigating the design and use of Interactive Web Applications (IWAs). Based on existing literature and empirical studies of use practices, we have shaped a typology for categorizing typical characteristics of IWAs. The paper draws primarily on preliminary findings regarding IWA use in a Danish bank. The main aim of the paper is to establish a toolkit for interdisciplinary studies and comparisons of use and design of various IWAs.

Keywords

Interactive Web Applications, categorization, interdisciplinary research, interactivity, intranets.

INTRODUCTION

This work-in-progress paper presents reflections upon an interdisciplinary research via the DIWA-program, an acronym for *Design and use of Interactive Web Applications*. The program runs for four years (1999-2003), is supported by the Danish Research Council, and consists of 17 senior and junior researchers from four Danish Universities: The Technical University of Denmark, The University of Copenhagen, Roskilde University and The IT-University of Copenhagen.

The main theme of the research program is to investigate how design, management and use of Interactive Web Applications

- intra- or extranets - in different work settings may change the practice of information system development. A central purpose of the DIWA-program is to develop implementation models, best practice guidelines and conceptual frameworks, which may support the design and management of IWAs. The research is constituted by a wide range of theoretical frameworks and in depth empirical studies in a number of Danish private and public organizations - use as well as development organizations.

Based on the overall theme, the DIWA-program has four objectives:

"1. To examine how the scope, content, and organization of IS development processes change when information services become ubiquitous and software development coalesce with media design;

2. To analyze the implications for the division of labor, skills, and knowledge in IS development;

3. To identify key organizational and technical factors that facilitate or impede successful implementation of interactive WIS; and

4. To develop concepts, methods and tools to guide both the development of interactive WIS and the development of new, distributed and networked, organizational forms." [5].

In order to conduct interdisciplinary research and achieve the objectives above it is necessary to establish common grounds for discussion and comparison of research findings. The DIWA research project encompasses computer scientists, media researchers, economists, sociologists, ethnographers, and psychologists who contribute with different perspectives

on how an IWA may be defined and studied. One way in which these perspectives may intersect is to formulate categories for characterizing IWAs - from which empirical explorations may depart. The aim of this paper is thus to put forth a set of categories that may be applied, firstly, to locate IWAs relevant for study in empirical settings, and secondly, as a guideline for engaging in these empirical studies.

PINPOINTING IWAS

Interactive Web Applications (IWAs) comprise a relatively new type of information systems based on Internet standards and protocols such as HTTP and TCP/IP. Such IWAs are currently being implemented in many larger commercial corporations, in governmental organizations, in schools, universities, hospitals etc.[1] Compared to the proliferation of this type of system, very little academic literature on the topic exists. Very few empirical studies of IWA development and use are available (e.g. [1], [3], [4], [8]), and the only literature to our knowledge providing a relatively comprehensive overview of the topic is an issue of the journal Communications of the ACM from 1998.

In the CACM journal various authors discuss the differences between Web-based information systems (WISs) and previously existing information systems (e.g. [6], [1], [12], [5]). Isakowitz et.al. [6], for example, defines a WIS through its negation - as fundamentally different from both Web pages and traditional information systems.

"There is a clear difference between a set of Web pages and a WIS. The latter support work and is usually tightly integrated with other non-WISs such as databases and transaction processing systems. WISs are also different from traditional information systems. They require new approaches to design and development, have the potential of reaching a much wider audience, and are usually the result of grass-roots efforts." [6].

The articles in CACM - as well as the DIWA research program - underline the fact that these differences present new and urgent challenges for system developers and designers, organizations management as well as individual users.

As noted above by Isakowitz et.al. [6], WISs allow for organizations to integrate different applications and join these in multi-modal Web-based user interfaces. A WIS may thus potentially function as the basic platform for many aspects of communication, coordination, cooperative work, and distributed knowledge sharing inside an organization (Intranets) as well as between organizations (Extranets). In this way existing information systems and applications applied in work continually become integrated, incorporated, and "remediated" [2]. WISs thus encompass a variety of communication and work media such as publishing, distribution systems and applications to support work groups and collaboration.

Due to this integration WISs potentially mediate a very wide range of interactions among human agents. This aspect is also emphasized in CACM and discussed in detail by Turoff and Hiltz [12] as "superconnectivity" between humans.

Within the DIWA program the term Interactive Web Application is applied instead of Web-based Information System. In doing this we direct the attention towards the applications and stress their interactivity. An application may hereby be defined as a set of functionalities utilized in a specific situation combined with diverse work practices.

Defining Interactivity Threefold

In order to understand the concept interactivity, we apply a distinction suggested by Jensen [7]. Drawing on sociological theory Jensen emphasizes that the concept should be divided into three types of interactivity based on the relationship between agent, structure and medium.

Agent - Structure: For our present purposes interaction among agent and structure can be labeled as interaction between people mediated by an IWA. Interaction between two users of a discussion forum is an example of agent-structure interaction. In this case, one can also speak of levels of interaction, e.g. a news publishing system being less interactive than a discussion forum because the consumer is not "acting".

Structure - Medium: This interaction concerns the way the introduction of an IWA may influence the social patterns of an organization and vice versa. Generally, applications like Virtual Offices[2] are less interactive than the IWAs we studied on the intranet of the bank. In the latter case, the social patterns of the communication is reflected in the IWA, simply because they are custom built at the IT department of the bank. This example is elaborated below.

Agent - Medium: This relationship refers to the ability of changing the system in the process of work, meaning that an IWA is interactive if it allows the user (agent) to change the IWA (medium). Some Virtual Offices offer the opportunity to create document types with custom data structures. In this case, as with agent-structure and structure-medium interaction, one can speak of levels of interaction between agent and medium. By way of illustration, the capability to create and name a folder is less interactive than creating standards by designing document types and data structures.

In addition to possibilities for application integration and the mediation of collaborative work, another important feature of IWAs is their flexible and emergent character. An active user role, noted above by Isakowitz [6] as "grass roots" characteristics can also be coined as a high level of agent - medium interactivity. IWAs often emerge through end-user computing

---

[1] IWAs or WISs also include e-commerce systems which are, however, not included in the DIWA program.

[2] Virtual Offices meaning shared electronic working spaces that are standards applications such as: HotOffice (http://www.hotoffice.com), BSCW (http://orgwis.gmd.de/projects/BSCW), Lotus Notes (http://lotus.com), and ProjectWeb (http://www.projweb.com)

and they allow users to publish and organize information as well as alter and construct aspects of the underlying systems – for example database or work flow content and structure. These malleable features imply an array of new challenges for system designers and users. And they may well also serve to blur the distinction between the two since users can also contribute to system development and design [9].

A FRAMEWORK FOR EMPIRICAL RESEARCH

In order to describe and understand an IWA we discuss different categories. Drawing on Bowker and Star [11], the IWA categories discussed below can be understood as boxes in which things can be put in order to carry out work and produce certain kinds of knowledge. These boxes will be applied as research guidelines and function as a shared conceptual framework for conducting and comparing the empirical studies within the DIWA program.

It is important to note that the categories or "boxes" assist a systematic segmentation of things and practices that do not necessarily meet requirements of total consistency, of mutual exclusivity between categories, or complete coverage in regards to what can be described [11]. Instead we emphasize that the categories discussed are compromises - the result of our ongoing negotiations where previous schemes of media and information systems are drawn upon and elaborated.

In building these categories we have been particularly inspired by previous DIWA seminars as well as the work of Meyrowitz [10] and Bolter and Grusin [2]. Meyrowitz' categories have been used as a starting point. We have adapted the categories from media studies to employ them in studies of IWAs. In the process we have modified, subtracted and added categories to suit our purposes to identify and describe IWAs.

Complexity of the Object

Computer-based media and especially web based media like IWAs have an unproceeded level of complexity in the relation between given technical parameters and the patterns of use emerging. We can hardly make a distinction between technical infrastructure and use or content as is the case with e.g. TV.

One central property of computer media is grasped by Bolter and Grusin [2] with the concept of remediation. The computer medium is said to remediate older media, using elements from newspapers, books, TV, radio etc. in creating computer based media. In regards to expression and communication patterns, a new level of flexibility emerges.

Another central property is the multi-layered constraints put forward by standards built into the IWAs. Perhaps the most interesting property of IWAs is their reliance on standards within a number of levels: TCP/IP and http at the network and communications layer, html, and xml at the content layer and the browser on the client side.

On the other hand, one may witness an interesting movement away from hardware bindings since a multitude of devices such as WAP-phones, PDA's, etc. can be connected to the same IWAs. Within TV, the protocols of broadcasting are given, whereas in the IWA, the software standards are given. Consequently the standards used with IWAs produce logical constraints while removing hardware constraints. This gives a new flexibility and of course a difficulty with categorizations.

As we mentioned earlier, an important feature of IWAs is the high level of interaction between agent and medium. This means, in other words, that the balance between design and use is shifting. The properties of the IWAs do not determine the actual use, nor is the actual use independent of the specific IWA. This makes it difficult to make a clear cut between the technical and non-technical in relation to the categorizations.

The Research Process

Having discussed some levels of constraint concerning IWAs as an object of study, we proceed to present constraints that influenced our work and resulted in the findings presented.

Firstly, it was difficult to get access to do research in certain organizations collaborating with the DIWA program. This difficulty had primarily to do with busy contact persons; projects in progress, which did not come through or was too classified, and/or with changes within the organizations such as business mergers. Secondly, and the most troublesome constrain, was the difficulty of locating IWAs - because, either, we did not know what precisely to look for, or, because the technology was not interactive "enough" - as the case with traditional information sites, which may be perceived as uni-directional interaction.

The last two mentioned constraints reflect the perplexity of being an interdisciplinary group, trying to figure out what qualifies the object of study and how to approach it. Discussions and negotiations about finding common ground for what we are looking for, which concepts to use, and what these might imply, have taken place.

Additionally, in trying to get a grasp of IWAs, we have examined and used different Virtual Offices - both as working tools and as study objects considered in relation to the applied media theory. The outcome of these practical experiences and theoretical explorations are presented here. Both by way of making the concept of interactivity flexible and manageable for capturing different facets of IWAs and by suggesting a framework of categories which can be applied in finding characteristics of IWAs.

To illustrate the use of these categories we give examples from one of the DIWA case studies. The case study concerns the intranet in a Danish Bank. The case study is based on three introductory meetings with the communication department and a series of interviews with employees in three head office sections and two center branches. A center branch func-

tions as a regional communication center for sub branches[3]. During the interviews the employees depicted their experiences with the intranet and demonstrated use. Additionally the material is based on the researchers surfing and as well as documentation of the structure and content of the intranet.

The overall aim of the intranet is to improve the communication in and between the employees in the departments in the head office, the central branches and their local sub-branches. The intranet studied consists of a number of different IWAs that can be analyzed both separately and as a whole. Based on the empirical material, were we will focus on a work guideline system and a discussion facility. So far the work guideline system has replaced a paper based information system with on-line manuals and electronic distribution of critical information and furthermore contains rules and guidelines for performing the highly structured work of the bankers. The intranet also includes a discussion facility where employees can raise topics in a news-group environment. This facility functions as a public space with little structuring.

IWA CHARACTERISTICS
To identify and distinguish different IWAs we propose the following categories:

Uni-, bi- or multi-directional transfer of information
This category may help us define whether and to which extent the IWA is interactive (agent-structure). We see the different types of directionality as a continuum, where a purely uni-directional application is not interactive in our understanding. The critical issue is whether the setting allows the user to receive as well as send information (i.e. decode/encode) in a reciprocal manner.

The issue of directionality may be organisational. A person, an organisational unit, a company or another group of people using an IWA plays either the role of contributor or reader. An uni-directional transfer, within traditional media theory, can be exemplified by the one way dialogue between broad caster and audience, which are to be found within e.g. television and newspapers. In the case of IWAs, uni-directional transfer is from one person/unit to another, which may be perceived as agent-structure interaction. Bi-directionality, in the traditional sense, can be illustrated by the two directional interchange one finds within the use of telephones. In relation to IWAs bi-directionality is between two persons/units who can both contribute and read, thus the interactivity may be found both at the agent-medium and agent-structure level. Lastly, multi-directionality refers to the dialogue and/or exchange between several persons/units.

In the bank studied the distribution of the on-line manuals, which contain guidelines for providing services to bank customers, seems to reflect a hierarchical top-down structure of the organization. The structure of the bank appears to be

[3] The findings are based on an internal report by Jørgen Bansler, Keld Bødker, Lars Kofod, Hanne Westh Nicolajsen & Jens K. Pors (2000), which is unpublished due to the anonymity of the bank.

divided into a developing and rule formulating center, which uses the intranet to direct the sub-branches. This means that the transfer of information in this case is uni-directional from center to periphery. This also applies to the transfer of the critical information, such as changes in legislation. The employees are obliged to check the intranet daily to read this kind of information.

The discussion facility of the intranet is however multi-directional, as it is possible for all the participants to contribute to the discussions. In the bank one of the most popular discussions has been about getting a PC at home financed by the bank.

Turn-taking - simultaneous and sequential interaction
Any form of interaction involves some kind of turn-taking rules either explicitly stated or implicitly acknowledged by the participants. Given an interactive application, identifying the turn-taking rules and characterizing the actual practice of turn-taking describes the ordering of the temporal aspects of the interaction. The rules for turn-taking can be implemented in the formal aspects of the system, role-allocated or emerge from actual use. These different types of communication may be found within one IWA and important aspects of the IWA can be characterized by scrutinizing the rules for turn-taking.

The categories of communication that are visible in the use of IWAs are remediations of well-known types such as monologue or TV-broadcasting (i.e. mailing-lists or web-publishing), dialogues and discussions among two or several participants (i. e. news-groups, chat forums, some forms of e-mail exchange or bulletin boards) and meetings for coordination of activities (i. e. CSCW-systems).

Within the different types of communication identified in an IWA degrees of simultaneous and sequential interaction can be distinguished. Simultaneous interaction is where the participants occupy the same (real or virtual) space at the same time e.g. working on a document simultaneously or discussing in a chat-like manner. Sequential interaction takes place when the interactions are no longer parallel, but ordered after each other in time.

The system for publishing the work guidelines as implemented in the intranet of the bank has explicitly stated rules for turn-taking in the associated production, distribution and reading practices. Since it is a publication system, which is to a large extent uni-directional it does not facilitate simultaneous interaction.

On the other hand the discussion facility of the intranet in The bank provides the possibility of simultaneous interaction in the news-groups. The observed use of the system shows the unwritten rules of turn-taking of the interaction, since there is a delay between the contributions much like normal face-to-face conversations. When chat-like communication takes place with quick turn-taking the discussions could come very close to simultaneous interaction if for example all the

employees at the same time would contribute to the discussion of i.e. home PCs.

In other IWAs (i.e. some CSCW-systems such as BSCW) the facilities for versioning control of shared documents provide the means for turn-taking. The configuration and actual use of the facilities of the IWA make the rules of turn-taking within a working group explicit.

Genre - language and style

Different IWAs use different means of expression and different languages. Languages should be understood here in the broadest sense as symbol systems. An IWA is typically combining graphical symbols with written text. Some IWAs use video and audio alongside text and pictures.

As noted above, IWAs apply all the means of expression of the old media, and thus borrows language and style from these older media. Different Virtual Offices, for example, remediate different existing setting, thus creating different styles. HotOffice models a traditional office with a desktop, phone messages and documents, whereas eRoom models a project war-room known from consultants engaged in short-term projects at a client.

Language and style is touching upon another aspect of interactivity. At the danish bank, they have created quite strict guidelines for how IWAs should be presented graphically and how text should be written for the intranet. We would say that this is a case of low interactivity between agent and medium since language and style is chosen centrally.

This issue of means of expression can also illustrate the issue of levels of constraint. At the bank, we have an example of how a specific combination of constraint on a hardware level create specific means of expression on the level of language and style. In the work guideline systems the insufficient bandwidth of the technical installations between the sub-branches and the head office of the bank prohibits the distribution of graphs and other visual information, since widespread use would cause the whole system to grind to a halt. As a consequence of this, rules have been made to limit the use of files containing large graphics. In some specific work areas these rules are constricting the ability to communicate complicated matters, i.e. graphs of recent developments in markets.

The organizational context - structure and practice

The design, implementation and use of IWAs can follow a top-down or bottom-up structure with implications for formal structures and actual practices in the organization. A top-down approach describes use and implementation initiated from management where as a bottom-up approach describes initiatives from the "grass-root" level.

The interaction between agents within the organizational structure can be supported through definition of new roles related to the IWA. The defined roles contain formalized rights and access priviligies to participate in the interaction

mediated by the IWA. Different levels of participation can be identified. One level is to initiate and moderate topics, another level is to contribute actively to them and a third level is mainly to receive and decode information. Users can thus participate at different levels and these levels can to some extent be built into the IWA. Examples are closed areas where people need special passwords to access the information or special rights to initiate, publish and delete material or whole areas administrated through the allocation of roles. The actual practice evolving around IWAs depends upon the skills, knowledge and motivation of the user, which implies a connection to the broader organizational context - coherence to work processes, educational efforts etc. This points to the processes of interaction between medium and the wider organizational context.

The work guideline system of the bank mainly consists of open areas, which means that everyone can access all the data bases as well as departmental web-sites. In the bank the restrictions divide those who can write and publish in the different information categories. Each department is in charge of specific information categories, which are connected to special work functions performed in the sub-branches. If a department wants to publish some information in the information category of another department, they have to get their information reviewed and accepted by an editor in the respective department "owning" the category. The same review and acceptance processes are applied to authors of the department.

Another restriction to keep control and coordination of information at the head office is a rule allowing only departments and center-branches to setup and run web-sites, while the sub-branches are impaired from this.

An example of new work practice evolving through the use of an IWA is seen in one of the center-branches. Here a new role as "information responsible" has been defined. The task of the "information responsible" is to read, sort and interpret information in the four main information categories from the head-office. This new role is not part of the central structured system but was invented locally to cope with the overwhelming load of information. In another center-branch they did not find the information load to heavy, which means that there are now different practices in the two center-branches.

The discussion facility is the only place where it is possible to have closed areas, where the initiator invites specific people to participate and can exclude all others. This facility is hardly used. The interviews indicate a lack of perceiving this as "proper work", as it does not support the main work processes and has not been marketed as a working tool.

To prepare the use of the work guideline system in the bank, the department of communication showed a video to present and market the application. In addition to this guidelines for the use of the intranet were made and distributed. The intranet coordinators were formally educated in the technical parts, to

make them able to support the use in their departments and sub-branches. Apart from this workers were forced to use the system and thus learn through practice as the former channels of information were closed.

Information architecture

An IWA is almost always structuring and presenting information (using different languages and styles). Some information is structured for the user while some is created and structured in the use process thus spectrum of agent – medium interactivity. Therefore the way the information is structured, navigatable, searchable etc. is a central category to be investigated.

Information in IWAs may be structured using hypertext principles (html) whilst some is structured in hierarchical (e.g. XML) or relational data structures. This provides very different possibilities for finding, reading, and manipulating information.

The information architecture of an IWA is concerned with how information can be navigated using e.g. hyperlinks. Navigation presuppose a structure, be it a tree-structure, network etc. The structure can be created by subject matter, author, time of publication etc.

The information architecture is also concerned with facilities for searching for information. Searches vary from very structured searches in database records to free text searches. Archiving and version control are other tools to improve the information architecture.

The difference between push and pull is central to information architecture. Notifications of the users of changes in an IWA is a way of providing push information in pull oriented systems. This is for example part of the BSCW application, where you get daily usage reports by e-mail.

The intranet of the bank we studied had a degree of personalization in the information architecture. Employees had their own startup page on the intranet with a possibility of adding and removing links to specific IWAs on the intranet. At the same time, the startup page was connected with the Human Ressource system of the bank, so that it was also used to direct information to specific job categories.

SUMMING UP THE CHARACTERISTICS

To identify and distinguish different IWAs we have proposed these categories, which form an analytical framework for characterising IWAs. The division of these five characteristics is not a clearcut one, since the categories are results of on-going discussions of empirical investigations and there are many overlaps and connections between them.

• Uni-, bi- or multi-directional transfer of information

• Turn-taking - simultaneous and sequential interaction

• Genre - language and style

• The organizational context - structure and practice

• Information architecture

In trying to characterize IWAs we are facing the classical problem of induction vs. deduction. Are we classifying phenomena by a definition or are we creating definitions by finding common properties of the phenomena? We have done both. At this stage our hypothesis is that IWAs are a type of application that shares interesting properties. At the same time we try to define common concepts to communicate about the different properties IWAs comprise.

FUTURE RESEARCH

It is our hopes that future research on IWAs - our own as well as that of others - may not just pour content in the boxes put forward, but rather spur further critical discussions on the nature and adequacy of such categories. Our own future research will be based upon in depth empirical studies of IWAs as these are produced and used in and may change organizational practices. As mentioned above the aim of the DIWA program is not only to build typologies but also provide new insights regarding use, development and change in structures of organizations.

The IWA categories presented are viewed as initial tools that may function as a toolkit for conducting empirical explorations and comparisons. As argued, it is vital to establish common grounds and agreements when engaging in interdiscplinary research. It is our suggestion that the categories above based on existing literature as well as our own empirical studies may guide and benefit further analyses and comparisons of IWA-like systems.

It is important to note that the categories suggested above are based on both literature - from the field of media studies, CSCW and systems development - and on own empirical research - concerning mainly user practices. The categories therefore revolve around use and might differ if these were based upon strictly computer science studies and design practices. As we proceed with these investigations, special attention will therefore be paid to the categories and metaphors designers and users themselves employ when describing IWAs and the work that surrounds and are embedded in these systems. How do their experiences compare to our classifications? We expect that such comparisons and further studies will reveal other technical features, use activities, and characteristics that are excluded in our terminology. Do user and designer experiences and problematics correspond? When initiating and designing IWAs designers make their own categories based partly on prior experiences of design and on technical standards and possibilities. A further development of the typology may thus also be applied to shed light not only on different IWA use practices but perhaps also on the work of designers and the categories implied in their practice.

251

REFERENCES

1. Balasubramanian, V. and Bashian, A. Document Management and Web Technologies: Alice Marries the Mad Hatter. *Communications of the ACM 41* (7) 1998, 107-115

2. Bolter, J.D. and Grusin, R. Remediation. *Configurations 4* (3) 1996

3. Cecez-Kecmanovic, D., Moodie, D., Busuttil, A. and Plesman, F. Organizational Change Mediated by E-mail and Intranet – an Ethnographic Study. *Information Technology & People 12* (1) 1999

4. Damsgaard, J. and Scheepers, R. P. Influence and Intranet Implementation: A Safari of South African Organizations. *Information Technology & People 12* (4) 1999

5. DIWA, Design and use of Interactive Web Applications, A proposal for the Danish Research Councils' Program on Information Technology, *http://www.diwa.dk* 1999

6. Isakowitz, T., Bieber, M. and Vitali, F. Introduction. *Communications of the ACM 41*(7) 1988 78-80

7. Jensen, K. B. Interactivities: Constituents of a Model of Computer Media and Communication. In Bondebjerg, (ed.) *Moving Images, Culture and the Mind,* University of Luton Press 2000.

8. Lamb, R. and Davidson, E. The New Computing Archipelago: Intranet Islands of Practice. In *Proceedings of IFIP TC8 WG8.2* (Aalborg, Denmark, June 2000)

9. Lyytinen, K., Rose, G., and Welke, R. The Brave New World of Development in the Internetwork Computing Architecture (InterNCA): or How Distributed Computing Platforms will Change Systems Development. *Information Systems Journal 8* 1998 241-253

10. Meyrowitz, J. Images of Media: Hidden Ferment-and Harmony-in the Field. *Journal of Communication 43*(3), 1993 55-66

11. Star, S. L. and Bowker, G. How things (actor-net) work: Classification, magic and the ubiquity of standards. *http://weber.ucsd.edu/~gbowker/actnet.html* 1996

12. Turoff, M. and Hiltz, S.R. Superconnectivity. *Communications of the ACM 41*(7) 1998, 116