CallMeSmart Becoming Ubiquitous and Self-learning

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Abstract – **A novel system for communication between hospital doctors, CallMeSmart-doctor (CMS-Dr), earlier referred to as CallMeSmart, has been developed and tested at a university hospital. The first version of CMS was dedicated to doctor-doctor communication. In this paper we discuss how we based on CMS-Dr can establish a generic CMS solution: A fundamental new ICT infrastructure for all health care actors (not only doctors), and other actors and sectors with complex, temporarily and time critical communication patterns. The CMS-generic shall become Ubiquitous and Self-Learning (CMS USL). The technological CMS-USL solution will represent the internationally forefront of ICT-research and development through new combination of advanced data-based wireless communication that maintains context awareness, in addition to ubiquitous and self-learning machine mechanisms.**

Keywords – Context-awareness; wireless devices; mobile communication; Interruption management; VoIP; Machine learning

I. INTRODUCTION

Physicians' working conditions rely on mobility. They move frequently between in-patient ward, outpatient ward, emergency ward, operating theatres, etc., and they often do not stay more than a few minutes in the same location. High mobility requires mobile communication systems, which enables physicians to communicate with colleges at any time and place, to avoid any delay between the decision made and action taken. Such delays could result in medical errors [1], and mobile communication systems have been suggested as a solution to improve communication in hospitals [2]. The challenge when deploying mobile communication systems is to handle the balance between the increased availability and possible interruptions [3]-[5]. Most hospitals still rely on a mobile communication infrastructure with dedicated devices for each role, where pagers are the most dominant mobile communication devices.

Pagers provide a cheap and reliable way for contacting staff members. They are ubiquitous and several physicians carry numerous pagers simultaneously to cover the various work roles they have been assigned. Pagers suffer from a number of problems due to their simplicity. The most obvious limitation is that it requires the staff to locate a telephone (landline or wireless) in order to respond to a page. This might cause unnecessary delays and communication overhead, since the person placing the page is not always near the phone when the page is returned [6]. Pagers also create a large amount of unnecessary interruptions [7][8], which is unpleasant and can cause medical errors [1].

The most intuitive solution to improve the communication situation in hospitals is to provide physicians with wireless phones. However, phones can be even more interruptive than pagers [3]-[5]. In [3], a physician states that; "with a pager you just have to glance down at your coat pocket to see who is paging, while with a phone, you have to pick it up from your pocket to see who is calling. Having done that, it is easier just answering and explaining that you are busy" [4].

Preliminary studies points at a diversity of potential benefits from wireless phones in hospital settings, using both mobile text and voice services [6][9]-[11]. These studies also reveal potential technological limitations that can explain some of the challenges of gaining acceptance. Text-chat is a less obtrusive medium than other forms of workplace communication [12]. It is therefore unlikely that mobile text messaging creates the same amount of interruptions as mobile voice services. Improved asynchronous communication systems have in fact been recommended for improving hospital communication practices [2]. In addition to mobile synchronous communication systems, mobile text-messaging systems are therefore an interesting medium to explore in hospitals settings.

However, the current generation of mobile-text messaging systems is no suited for hospital environments. Studies of mobile text-messaging usage in hospitals have, revealed difficulties related to small screen size [10], and problems related to forcing doctors to carry an additional device [9]. It has to be taken into account that these studies are some years old. Today displays and keyboards are significantly improved, which might have changed the situation. A continual problem with mobile text messaging is that senders often need an acknowledgement that an asynchronous message has been read by the receiver [2]. The acknowledgement challenge could be solved by a forced feedback when the message has been opened. Automatic suggestions for replies may ease the difficulties with text-

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messages. It has been reported that predefined messages can meet up to 90% of the mobile text-messaging needs for some hospital workers [13].

Mobile communication systems for hospitals represent an important research area since hospitals are noted to suffer from poor communication practices. The combination of wireless phones and fact that hospital workers seam to exert interruptive communication patterns before non-interruptive methods [2][7][8] and often exhibit a "selfish" and interruptive communication practice, may result in unnecessary interruptions for conversations that otherwise would' not occur [14]. This amplifies the risk of overloading limited resources with special knowledge, experience, and the power of taking medical decisions. The balance between getting immediate access to resources and causing interruptions in moments where it is not appropriate, has similarities with the classical problems regarding collaboration and sharing of resources, such as of disparity in work and benefit, "prisoner's dilemma" and "the tragedy of the commons" [15]. A critical issue for voice services is the potential of make people "fatally available" [6], which cannot be overlooked since health care is a knowledge intensive activity where consulting colleagues or senior staff members is a necessity in many situations [16].

One way of attacking this problem is to provide the caller with context information from the receiver's situation. Context information could be any kind of information which helps to decide if the receiver is available or not, such as; location, activity, surrounding noise, role, etc. In a study by Avrahami et al. [17], they revealed that if the caller is provided with context information about the receiver's situation, it reduces the mismatch between the caller's decision and the receiver's desires.

A number of studies have focused on context-sensitive systems for hospitals. The work done on context-sensitive mobile communication within hospital settings has identified some important elements of context, including location, role, delivery timing and artifact location, and user state [18]. This model has been applied to an instant messaging system based on PDAs enabling contact based on these contextual elements. This approach, however, requires workers to carry additional mobile devices in order to support voice and paging services, since it is not compatible with existing hospital communication infrastructure.

A variety of models for detecting interruptibility have been created for stationary [19][21] and mobile settings [22]-[24]. In general, these models focused on office workers and social settings, and used information such as a user's calendar, interactions with computing devices, switches to determine if doors are open, accelerometers, microphones and motion sensors. Accuracy rates of approximately 80% to 90% have been reported for directly predicting interruptibility and user state, such as "standing" or "walking", and social context, such as "lecture", "conversation", etc. None of these models, by our knowledge, has been explored in health care settings, and there are several factors which suggest that new health care models need to be developed. First, studies on context-aware communication for hospitals suggest information not included in these interruptibility models, such as work role, are critical for detecting proper context in health care settings [18]. Second, another issue is elements, such as location and social relationships, that are inherently different within health care, and need to be accounted for in health care appropriate models. For example, scenarios such as "visiting patients", "in surgery", etc. need to be considered in combination with the work roles of the person initializing the contact and the contacted person.

In addition, appropriate forms for user-interaction on interruptibility models also need to be investigated. It has been reported that users tend to use the information provided about a person's availability for communication, as a presence indicator instead of using it to control interruptions. This suggests that automatic configuration of devices may be the most appropriate approach [25]. The "SenSay" context-aware mobile phone [23] uses a hybrid approach that automatically blocks calls, and also generates text messages notifying the caller that their call have been blocked. Then they are allowed to override the blocking by calling back within a predetermined number of minutes from the same phone number. This problem needs to be reinvestigated in health care settings, since there are some situations where certain calls should not be blocked (such as those for a specific role) whereas other calls may need to be restricted. Thus, the context of both the caller and person being called will need to be considered.

The use of semi-structured messages has shown to be particularly useful for work coordination [26]. Preliminary studies have estimated that up to 90% of mobile text-messages used by hospital workers could be met by the use of such messages [13]. However, we have not been able to find any published work on the style and function of such messages, nor any studies that demonstrate if they would actually be adopted, or if they would have any effect during real work practice. The possibility to create automatic replies, and suggestions for replies, is also an advantage when using predefined messages, but the appropriate replies have not been studied in the context of mobile-text messaging. This could be particularly useful within health care settings, since such replies actually offers acknowledgement when a message has been read [2].

The paper is organized as follows: Status of Knowledge, which will include state of the art and a section about Ubiquitous self-learning computing, methods, which will explain the different method approaches we plan to use, approaches and hypotheses, and then a section to conclude the project.

II. STATUS OF KNOWLEDGE

We know from earlier studies within health care, but also from our own studies [3]-[5], that physicians in hospitals are interrupted unnecessary by mobile devices in situations where such interruptions should be avoided. One of the problems applicable for most of the earlier systems developed was that they required both new devices and infrastructures, and/or were based on public networks, like GSM/3G, which in both cases require considerable investments. A system based on existing infrastructure and

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devices used in hospitals would be much cheaper, and will probably require less training and maybe less resistance from health care workers when introduced. This is important, since early studies show that over half of medical informatics systems fail because of user and staff resistance [27]. We believe that by knowing and understanding the health care workers' work situation, the nature of unnecessary interruptions, and also by involving the participants in the design process, it is possible to build a system suited for their communication patterns and work situations on top of an existing communication infrastructure using devices already in use at hospitals. Our studies [3]-[5] contributed to such knowledge, and were used as input when designing and developing the context sensitive system for doctor's mobile communication, CMS-Dr [28][29].

The CMS-Dr prototype focuses on context sensitive interfaces, middleware, and new interaction forms for mobile devices that support multi-modal communication in hospitals. These devices support media such as voice services, text-messaging and paging services, in an efficient and non-interruptive manner, as well as enable support for individual and role-based contact on a single device. That is, the user only needs to carry one device for both personal and role based communication, which enables other users to, for example, contact someone assigned as "on-call" duties at a specific department, even if they do not know who that person is. At the same time, it aims at balancing between availability and interruptions, while it enables acute calls and alarms be forced through. Currently, by our knowledge, similar devices are not generally available for internal communication systems in hospitals.

The prototype senses the context automatically from different sensors, calendar information, work schedule, etc., to change the physicians' availability and the phones profile, according to the collected context information. At the same time, the caller is given feedback about the physicians' availability, and thereby it is possible for the caller to force through an emergency call, or forward the call to another physician at the same level, that is available. The system is based on ideas from existing research on interruptions, in combination with our ideas presented in [4][30]-[34]. A first version of the prototype is ready and has been tested in lab-settings with physicians as test users. The tests were performed as scenarios observed from real situations. The feedback was positive and has been used as input for improvement and further development of the prototype. CMS-Dr prototype is ready for testing in clinical settings, and a pilot was launched in May 2014, at the Oncology Department at the University Hospital of North Norway (UNN). The solution has so far retrieved overwhelming enthusiasm and positive response from the test users.

A. *Ubiquitous self-learning computing*

Ubiquitous computing, also denoted as pervasive computing, calm technology, or ubicomp, was first described by Mark Weiner et al. [35] as a technology "*which informs but doesn't demand our focus, or attention*". The principles of this technology are [36]: The purpose of a computer is to help you do something else; The best computer is a quiet and invisible servant; The more you can do by intuition, the smarter you are; The computer should extend your unconscious; Technology should create calm. In 2009, Stefan Poslad proposed a Smart DEI model to describe the ubiquitous computing built around three layers [37]: Smart Devices, smart Environments and smart Interactions. Smart devices provide sensitive information in order to enable automated dynamic service delivery like sensors or smartphones [37][38]. A smart environment is "*able to acquire and apply knowledge about an environment and to adapt to its inhabitants in order to improve their experience in that environment*" [39] by using smart devices [37]. Smart interactions enhance the device communication, the human machine interaction by acquiring, and disseminating the information provided by the smart devices and environments [37]. By using these three layers, a ubiquitous computing system could be predictive, self-learning and provide decision-making services, as Weiner has proposed [40].

To realize ubiquitous self-learning computing for pattern recognition and analysis we will make use of machine learning mechanisms. Machine learning has had tremendous success in intelligent systems design and modern technology [41]. One example is the Kinect® full-body tracking system used on the Xbox® games console, providing real-time tracking of the human body using machine learning techniques. The key principle is for the machines to learn from data related to the task to be solved [42]. This enables flexible systems with the ability to adapt and update themselves based on input and corrections from their environments. At University of Tromsø – The Arctic University of Norway (UiT), there is a strong activity on machine learning, focusing in particular on information theoretic learning criteria [43]. This versatile approach has lead to several award-winning publications [44].

III. METHODS

Each step of the project is conducted in three phases, which are constructed in order to ensure that users are involved as much as possible in designing and evaluating the systems targeted by the project. The three phases are observations & interviews, scenarios, and prototyping & effect studies. The approaches will be used in a complementary and iterative fashion.

A. *Observation and interviews*

Creating technology that will work in practice requires a thorough understanding of how technology is used in the workplace. The project will use techniques from Computer Supported Cooperative Work (CSCW) including observations of actual activities, conducting interviews with users [45]-[49] and performing workplace studies. This methodology has recently been advocated for improving medical informatics research [50] and will be used in the project in order to construct preliminary scenarios to present to users during design sessions, and also to investigate qualitative aspects of prototype systems during use in real work environments.

B. Scenarios

A scenario driven approach to research revolves around analyzing specific scenarios and use-cases [51] and subsequently, building technologies in order to serve those use cases. Scenarios in design [52][53] emphasizes both technical and non-technical aspects of systems design. This is especially important when dealing with technologies requiring changes in large and complex organizations. Observations and interviews with workers while using prototypes may reveal information that can be used to define new scenarios worth investigating.

C. Prototyping

Prototype systems will be developed and tested, further developed and evaluated both in laboratory and in real settings. Prototypes will be used in order to demonstrate the feasibility of proposed technical systems, in order to conduct effect studies, and will be deployed during real work practice.

D. Effect studies

Studies analysing the effects of technology on users that are consistent with practices in human computer interaction and information systems will also be conducted. Alternative user-interface designs for example will be evaluated using metrics such as completion time and error-rates for specific tasks.

IV. Approaches and hypotheses

The first research challenge in this project is to generalise CMS-Dr for other professions within hospitals. The second research challenge is to make the system intelligent through pattern recognition, pattern analysis and machine learning (CMS-USL). The intelligence is necessary to identify and analyse the bottlenecks in interaction patterns, unclear interaction patterns, and for the CMS-system to adapt to changing interaction patterns. The interaction pattern in hospitals is under constant change; role changes, tasks changes and responsibility changes. For example, when new IT solutions are introduced, e.g., the new structured EPR system that will be introduced to around 80 % hospital-employees in Norway in 2015 and 2016, roles, tasks and responsibilities will changes as the structured EPR is introduced. Hospitals are complex organisations, but we believe that if we can get CMS to fulfil and adapt to hospitals complex and continually changing communication demands, it will be easier to generalize CMS to the usage in less complex organisations. Therefore, the third research challenge is to generalize the solution to fulfil the usage of CMS outside hospitals. The fourth research challenge is that health care workers need to manually search for needed patient information from EPR systems. The future systems should use context awareness to automatically find the needed information when appropriate, e.g., when the doctor approaches a new patient during his visit, this patient's EPR would automatically pop-up on the doctor's smartphone/tab.

The overall aim is to deliver all the resources required (human, materials, information etc.) for a specific process (e.g. heart surgery) at the right time, to the right person, in a just-in-time configuration. The overall research goals are (1) to establish new knowledge about automatic machine learning and user modelling for complex, temporarily and time critical communication patterns in hospitals and similar organization in which roles and responsibilities, and therefore also the communication patterns, change from time-to-time, and (2) improving intramural communication in a university hospital, which will be the test bed for this project.

For the latter, we will establish a generic CMS solution, a new ICT-research and communication infrastructure for all health care actors and for other actors and sectors with complex, temporarily and time critical communication patterns. This will require various theoretical and methodological approaches, including requirements engineering methods for ubiquitous systems [54].

V. Conclusion

The overall aim of this project is to develop a complete system for a specific process at the right time, to the right person, in a just-in-time configuration. To do this, we need to understand the complexity of the hospitals organization, their communication patterns, analyse the bottlenecks, and thereby adjusting CMS to fulfil and adapt to hospitals complex and continually changing communication demands. The interaction pattern in hospitals are under constant change, and it is therefore important for future systems to make use of context awareness to automatically find and include the needed information when appropriate.

References

[1] W. Hersh, M. Helfand, J. Wallace, D. Kraemer, P. Patterson, S. Shapiro, and M. Greenlick, "A systematic review of the efficacy of telemedicine for making diagnostic and management decisions," *J Telemed Telecare,* vol. 8, no. 4, pp. 197-209, August 1, 2002, 2002.

[2] E. Coiera and V. Tombs, "Communication behaviours in a hospital setting: an observational study," *BMJ*, vol. 316, no. 7132, pp. 673-676, February 28, 1998, 1998.

[3] J. Scholl, P. Hasvold, E. Henriksen, and G. Ellingsen, "Managing Communication Availability and Interruptions: A Study of Mobile Communication in an Oncology Department," *Pervasive Computing*, pp. 234-250, 2007.

[4] T. Solvoll and J. Scholl, "Strategies to reduce interruptions from mobile communication systems in surgical wards," *Journal of Telemedicine and Telecare,* vol. 14, no. 7, pp. 389-392, 2008.

[5] T. Solvoll, J. Scholl, and G. Hartvigsen, "Physicians Interrupted by Mobile Devices in Hospitals: Understanding the Interaction Between Devices, Roles,

and Duties," *Journal of Medical Internet Research*, vol. 15, no. 3, pp. e56, 2013.

[6] P. A. Spurck, M. L. Mohr, A. M. Seroka, and M. Stoner, "The impact of a wireless telecommunication system on time efficiency," *J Nurs Adm*, vol. 25(6), pp. 21-26, Jun, 1995.

[7] N. J. Blum and T. A. Lieu, "Interrupted care. The effects of paging on pediatric resident activities," *Am J Dis Child*, vol. 146, no. 7, pp. 806-808, July 1, 1992, 1992.

[8] M. H. Katz and S. A. Schroeder, "The sounds of the hospital. Paging patterns in three teaching hospitals," *N Engl J Med*, vol. 319, no. 24, pp. 1585-1589, December 15, 1988, 1988.

[9] R. D. Acuff, L. M. Fagan, T. C. Rindfleisch, B. J. Levitt, and P. M. Ford, "Lightweight, Mobile E-Mail for Intra-Clinic Communication."

[10] S. A. Eisenstadt, M. M. Wagner, W. R. Hogan, M. C. Pankaskie, F. C. Tsui, and W. Wilbright, "Mobile workers in healthcare and their information needs: are 2-way pagers the answer?." pp. 135-139.

[11] A. Minnick, K. Pischke-Winn, and M. B. Sterk, "Introducing a two-way wireless communication system," *Nurs Manage* vol. 25(7), pp. 42-47, 1994

[12] E. Bradner, W. A. Kellogg, and T. Erickson, "The adoption and use of \“BABBLE\”: a field study of chat in the workplace," in Proceedings of the Sixth European conference on Computer supported cooperative work, Copenghagen, Denmark, 1999, pp. 139-158.

[13] J. E. Bardram and T. R. Hansen, "The AWARE architecture: supporting context-mediated social awareness in mobile cooperation," in Proceedings of the 2004 ACM conference on Computer supported cooperative work, Chicago, Illinois, USA, 2004.

[14] J. Parker and E. Coiera, "Improving Clinical Communication: A View from Psychology," *J Am Med Inform Assoc*, vol. 7, no. 5, pp. 453-461, September 1, 2000, 2000.

[15] J. Grudin, "Groupware and social dynamics: eight challenges for developers," *Commun. ACM*, vol. 37, no. 1, pp. 92-105, 1994.

[16] E. Coiera, "When Conversation Is Better Than Computation," *J Am Med Inform Assoc*, vol. 7, no. 3, pp. 277-286, May 1, 2000, 2000.

[17] D. Avrahami, D. Gergle, S. E. Hudson, and S. Kiesler, "Improving the match between callers and receivers: A study on the effect of contextual information on cell phone interruptions," *Behaviour & Information Technology*, vol. 26, no. 3, pp. 247 - 259, 2007.

[18] M. A. Munoz, M. Rodriguez, J. Favela, A. I. Martinez-Garcia, and V. M. Gonzalez, "Context-aware mobile communication in hospitals," *Computer*, vol. 36, no. 9, pp. 38-45, 2003.

[19] J. Fogarty, S. E. Hudson, C. G. Atkeson, D. Avrahami, J. Forlizzi, S. Kiesler, J. C. Lee, and J. Yang, "Predicting human interruptibility with sensors," *ACM Trans. Comput.-Hum. Interact.*, vol. 12, no. 1, pp. 119-146, 2005.

[20] E. Horvitz, P. Koch, C. M. Kadie, and A. Jacobs, "Coordinate: Probabilistic forecasting of presence and availability," in Proceedings of the 18th Conference in Uncertainty in Artificial Intelligence (UAI'02), 2002, pp. 224-233.

[21] E. Horvitz and J. Apacible, "Learning and reasoning about interruption," in Proceedings of the 5th international conference on Multimodal interfaces, Vancouver, British Columbia, Canada, 2003, pp. 20-27.

[22] A. Bernstein, P. Vorburger, and P. Egger, "Direct Interruptablity Prediction and Scenario-based Evaluation of Wearable Devices: Towards Reliable Interruptability Predictions."

[23] D. Siewiorek, A. Smailagic, J. Furukawa, A. Krause, N. Moraveji, K. Reiger, J. Shaffer, and F. Wong, "SenSay: a context-aware mobile phone." pp. 248-249.

[24] N. Sawhney and C. Schmandt, "Nomadic radio: speech and audio interaction for contextual messaging in nomadic environments," *ACM Trans. Comput.-Hum. Interact.*, vol. 7, no. 3, pp. 353-383, 2000.

[25] J. Fogarty, J. Lai, and J. Christensen, "Presence versus availability: the design and evaluation of a context-aware communication client," *Int. J. Hum.-Comput. Stud.*, vol. 61, no. 3, pp. 299-317, 2004.

[26] T. W. Malone, K. R. Grant, K.-Y. Lai, R. Rao, and D. Rosenblitt, "Semistructured messages are surprisingly useful for computer-supported coordination," *ACM Trans. Inf. Syst.*, vol. 5, no. 2, pp. 115-131, 1987.

[27] J. G. Anderson, *Evaluating Health Care Information Systems: Methods and Applications*: Sage Publications, Inc., 1993.

[28] T. Solvoll, L. Gironi, A. Giordanengo, and G. Hartvigsen, "CallMeSmart: A VoIP Softphone on Android Based Mobile Devices Using SIP," *eTELEMED 2013, The Fifth International Conference on eHealth, Telemedicine, and Social Medicine*, 3, pp. 198-203: International Academy, Research and Industry Association (IARIA), 2013.

[29] T. Solvoll, L. Gironi, and G. Hartvigsen, "CallMeSmart: An Ascom/Trixbox Based Prototype for Context Controlled Mobile Communication in Hospitals." pp. 1-4.

[30] T. Solvoll, S. Fasani, A. B. Ravuri, A. Tiemersma, and G. Hartvigsen, "Evaluation of an Ascom/trixbox system for context sensitive communication in hospitals." pp. 49-53, 2010.

[31] T. Botsis, T. Solvoll, J. Scholl, P. Hasvold, and G. Hartvigsen, "Context-aware systems for mobile communication in healthcare - A user oriented approach," *Proceedings of the 7th Wseas International Conference on Applied Informatics and Communications*, pp. 69-74, 2007.

[32] A. Talaei-Khoei, T. Solvoll, P. Ray, and N. Parameshwaran, "Policy-based Awareness Management (PAM): Case study of a wireless communication system at a hospital," *J. Syst. Softw.*, vol. 84, no. 10, pp. 1791-1805, 2011.

[33] A. Talaei-Khoei, T. Solvoll, P. Ray, and N. Parameshwaran, "Maintaining awareness using policies; Enabling agents to identify relevance of information," *J. Comput. Syst. Sci.*, vol. 78, no. 1, pp. 370-391, 2012.

[34] T. Solvoll, A. Tiemersma, E. Kerbage, S. Fasani, A. B. Ravuri, and G. Hartvigsen, "Context-sensitive Communication in Hospitals: A User Interface Evaluation and Redesign of Ascom Wireless IP-DECT

Phones," in eTELEMED 2011, The Third International Conference on eHealth, Telemedicine, and Social Medicine, Gosier, Guadeloupe, France, 2011, pp. 37-46.

[35] M. W. a. J. S. Brown. "Designing Calm Technology," January 8th, 2015; http://www.ubiq.com/hypertext/weiser/calmtech/calmtech.htm.

[36] "Pervasive Computing," January 8th, 2015; http://mbcbs.weebly.com/uploads/1/0/9/0/1090057/per_unit_1.pdf.

[37] S. Poslad, *Ubiquitous Computing: Smart Devices, Environments and Interactions*: Wiley, 2011.

[38] C. Noda and T. Walter, "Smart Devices for Next Generation Mobile Services," *Construction and Analysis of Safe, Secure, and Interoperable Smart Devices*, Lecture Notes in Computer Science G. Barthe, L. Burdy, M. Huisman, J.-L. Lanet and T. Muntean, eds., pp. 192-209: Springer Berlin Heidelberg, 2005.

[39] D. Cook and S. Das, *Smart Environments: Technology, Protocols and Applications (Wiley Series on Parallel and Distributed Computing)*: Wiley-Interscience, 2004.

[40] M. Weiser, "The computer for the 21st century," *SIGMOBILE Mob. Comput. Commun. Rev.*, vol. 3, no. 3, pp. 3-11, 1999.

[41] C. M. Bishop, "Artificial Life," *Life*, vol. in press, 2014.

[42] C. M. Bishop, *Pattern recognition and machine learning*: springer New York, 2006.

[43] R. Jenssen, "Entropy-Relevant Dimensions in the Kernel Feature Space: Cluster-Capturing Dimensionality Reduction," *Signal Processing Magazine, IEEE*, vol. 30, no. 4, pp. 30-39, 2013.

[44] R. Jenssen, "Kernel Entropy Component Analysis," *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, vol. 32, no. 5, pp. 847-860, 2010.

[45] E. Coiera, "Four rules for the reinvention of health care," *BMJ*, vol. 328, no. 7449, pp. 1197-1199, May 15, 2004, 2004.

[46] G. Button and P. Dourish, "Technomethodology: paradoxes and possibilities," in Proceedings of the SIGCHI conference on Human factors in computing systems: common ground, Vancouver, British Columbia, Canada, 1996, pp. 19-26.

[47] G. M. Murtagh, "Seeing the "rules": preliminary observations of action, interaction and mobile phone use," *Wireless world*, pp. 81-91: Springer-Verlag New York, Inc., 2002.

[48] K. Nygaard, "Program Development as a Social Activity." pp. 189-198.

[49] B. Shneiderman, "Leonardo's laptop: human needs and the new computing technologies," in Proceedings of the 14th ACM international conference on Information and knowledge management, Bremen, Germany, 2005, pp. 1-1.

[50] W. Pratt, M. C. Reddy, D. W. McDonald, P. Tarczy-Hornoch, and J. H. Gennari, "Incorporating ideas from computer-supported cooperative work," *Journal of Biomedical Informatics*, vol. 37, no. 2, pp. 128-137, 2004.

[51] A. Cockburn, *Writing Effective Use Cases*: Addison-Wesley Professional, 2000.

[52] J. Carroll, M. B. Rosson, and P. McInerney, "Scenarios in practice," in CHI '03 extended abstracts on Human factors in computing systems, Ft. Lauderdale, Florida, USA, 2003, pp. 1046-1047.

[53] J. M. Carroll, "Making use: scenarios and scenario-based design," in Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques, New York City, New York, United States, 2000, pp. 4.

[54] Tom, et al., *REUBI: A Requirements Engineering method for ubiquitous systems.* Sci. Comput. Program., 2013. **78**(10): pp. 1895-1911.