Review of HCI literature 1990 - 1999

This literature overview is taken by M. Rauterberg from the second chapter of the PhD thesis of A.D. Hunt.

Each of the following journals was reviewed by Hunt for the ten-year period 1990-99, giving a total of 1374 published papers:

- Behaviour and Information Technology
- Human Computer Interaction
- Interacting with Computers
- International Journal of Human Computer Interaction
- International Journal of Human-Computer Studies (formerly Man-Machine Studies).

Categories of HCI Literature

Every paper was placed into one of 23 categories according to its main subject. These categories were created and refined as the survey progressed. Many papers addressed several issues, but each was placed in only one category according to its central focus.

Figure 1 shows the relative numbers of papers in each category (as a percentage of the total number of papers reviewed). The categories shaded black are those regarded as potentially relevant to this study. In the discussions which follow, these relevant areas are examined in detail.
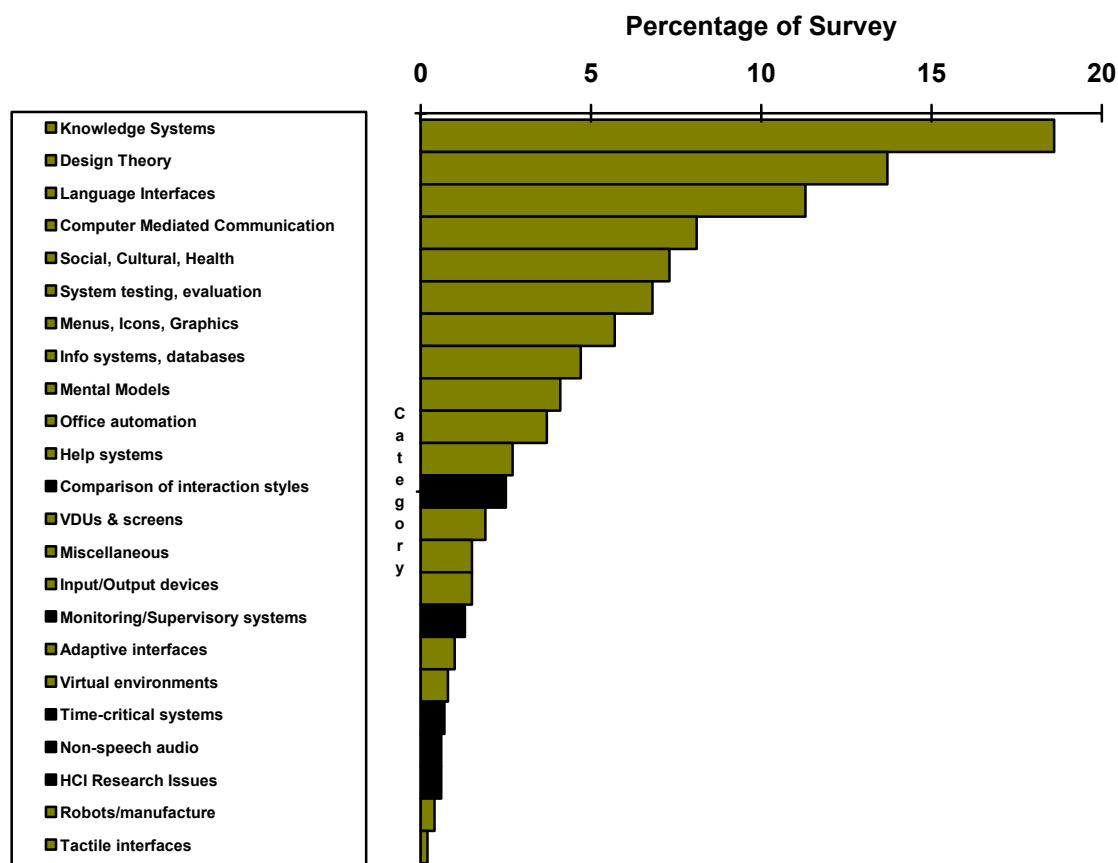

Figure 1: Percentage breakdown of HCI categories from survey

Author: A D Hunt, Department of Electronics, University of York, UK, ca 1999

Consideration of Relevant Areas

The survey has highlighted 23 different categories in the published HCI field. Each of these categories is now expanded and the key papers summarised. Each of the categories is now described, in decreasing order of percentage coverage. The actual percentage is shown in brackets after the title.

1 Knowledge-Based Systems & Theory (18.6%)

Consisting of nearly one fifth of the HCI literature since 1990, this area covers all aspects of the gathering, storage, processing and retrieval of knowledge. Subtopics include examples of 'Knowledge-Based Systems '(KBS), 'Decision Support Systems', 'Knowledge Theory', 'Expert Systems' and 'Artificial Intelligence' (AI). Typical paper titles are *Measuring the Value of Knowledge* [Reich, 1995] and *Fuzzy Sets Based Knowledge Systems* [Santamarina, 1991].
A few papers concern the use of expert systems in safety-critical situations. Lin et al [1998] acknowledge that;

> *"The management of emergency situations often requires human operators to make prompt and accurate decisions under stringent time conditions."*

[Lin, 1998]

They explain that people opt for the most easily accessible menu options (i.e. they do not take the time to search for the most appropriate option). However, rather than considering whether menus are the most appropriate interface, their focus is on making an expert system that comes up with a better set of options.

2 Design Theory & Software Engineering (13.7%)

One of the main focuses of HCI is in developing theories and applications which help designers of computer systems. The three areas covered by this category are that of general design theory, software design (software engineering) and programming. Typical papers in this section include *Cognitive Activities in Design* [Lee, 1994] and *Programming Strategy* [Davies, 1993].
Very few papers address the needs of interactive control system design. Johnson & Harrison [Johnson, 1992] argue for a theory of temporal logic to enable scientific proof of real-time system design.
Colgan et al [1995] describe a method of allowing the human designer to visually interact with an auto-design program in a similar manner in which a pilot monitors an autopilot.
Faconti [1996] presents a framework for analysing inputs that come from more than one device.

> *"User interfaces of many application systems have begun to include multiple devices which can be used together to input single expressions. Such interfaces . . . are commonly labelled **multimodal** because they use different types of communication channels to acquire information".*

[Faconti 1996]

The type of multimodal input featured is gesture-enhanced speech such as the statement "Put that there" where the user points to 'that' and 'there'. This is not directly related to this thesis, but it is interesting to note that designers are beginning to think in terms of multimodal inputs.

3 Language Interfaces: Text, Speech, Hypertext/media (11.3%)

This popular category covers the interaction between humans and computers using language - either typed, clicked on (with a mouse) or spoken. Papers range from *Automatic Speech Recognition in Practice* [Jones, 1992] and *Errors in Natural Language Dialogue* [Veronis, 1991] to the subtleties of text editing, for example *Blinking Cursor* [Coll, 1993] (which compares word-processors with and without blinking cursors).
The increasing use of the World Wide Web has dramatically increased the studies into how hypertext can be designed and enhanced. Example papers in this area are *Spatial Metaphors and Disorientation in Hypertext Browsing* [Kim, 1995] which considers the user of spatial cues to help people remain oriented when browsing. Shneiderman [1997] discusses how we cope with this new flood of information that comes with the World Wide Web.

4 Computer Mediated Communication (8.1%)

The topics of 'Computer Mediated Communication' (CMC) and 'Computer Supported Co-operative Work' (CSCW) are gaining increasing importance now that people are working in distributed

Author: A D Hunt, Department of Electronics, University of York, UK, ca 1999

locations, yet still requiring human-human collaboration and conversation. Generally CMC regards the computer as a communication device e.g. *Text-Based On-Line Conferencing* [McCarthy, 1993] and *Live Audio-visual Communication Systems* [Colbert, 1995].

CSCW implies that several people are working in a computer-supported environment. Examples of this are *Managing Design Ideas with a Shared Tool* [Lu, 1993] and *Interpersonal Communication and HCI* [Greatbatch, 1993] which complains of the limitations of "single-person, goal-oriented designs" that do not work in busy multi-person environments such as hospitals. Wambach [1995] studies the effect of email on an organisation's structure.

5   Social, Cultural and Health implications of computers (7.3%)

This increasingly popular topic relates to how computers are being accepted (or rejected) in society and what effects they are having on human health. Topics range from *Information Society and IT* [Kobayashi, 1991] to *VDT and Excretion* [Tanaka, 1992] which analyses the chemical content of users according to how much time they spend in front of a computer monitor! Emphasis is given to anxiety and stress in the computer-oriented workplace e.g. *Stress, Control and Computer-Based Work* [Wastell, 1996] and [Henderson, 1995].

6   System Testing & Evaluation (6.8%)

This topic covers all aspects of how software is tested and evaluated, with particular regard to the Human-Computer Interface, the environment in which the testing is to be done and various theories for analysing the results. Example papers include *Evaluating User-Computer Interaction* [Sweeney, 1993], and *Effects of Running Fewer Subjects* [Cordes, 1993].

Lin [1997] notes that *"well-designed computer software should be easy to learn",* whether by rote learning or understanding or explanation. Macleod's *The MUSIC performance measurement method* [1997] sounds very promising for this study, but actually describes a system for comparing banking tasks, MUSIC being an acronym for Measuring the Usability of Systems In Context!

7   Menus/Icons/Graphics (5.7%)

The graphical interface is still the main method for the display and editing of information. Much discussion takes place on the different types of graphics e.g. *Classifying Graphical Information* [Lohse, 1991] and how best to structure menus e.g. *Context in Hierarchical Menus* [Field, 1990] and *Pull-Down v Traditional Menu Types* [Cancy, 1996].

8   Information Systems & Databases (4.7%)

This category concerns 'information points' i.e. systems whose role in life is to allow people to have access to information. It would not be too far-fetched to include this topic as a subsection of category 2.5.3.1 (Knowledge-Based Systems) which would then constitute nearly a quarter of the entire HCI literature. A typical paper in this category is *Deriving Requirements for a Hospital Information System* [Symon, 1992]. As it stands, it simply provides an information point for patients and administrators. Databases are a special, more flexible, form of information point designed to hold and manipulate data at the user's requirements. *Retrieval of Images from Image Databases* [Whalen, 1995] explains how to look for trademarks which distinguish images from each other.

9   Mental Models (4.1%)

This topic covers those papers which discuss the psychology of what goes on inside the heads of humans. Much of this research is used to support the design of computer systems by 'modelling' the user's thoughts and actions at the design stage. Papers range from *A Descriptive Study of Mental Models* [Payne, 1991] to *Understanding Calendar Use* [Payne, 1993] which considers how humans represent time in their lives.

10   Office Automation & Business Applications (3.7%)

'Office Automation' (OA) is an accepted sub-branch of HCI, presumably because there is so much commercial pressure to improve and sell word-processors, accounting packages, spreadsheets and computer filing systems. Papers cover topics such as *Managerial Competence and New Technology* [Burnes, 1991] and *Learning to Use a Spreadsheet* [Kerr, 1994].

Author: A D Hunt, Department of Electronics, University of York, UK, ca 1999

11   Instruction & Help Systems (2.7%)

Systems or software which offer the user information or instruction are included here. Studies of 'Help' systems such as *Advice Giving and Following* [Hill, 1993] are included alongside computer-aided instruction features such as *Animated Demonstrations* [Palmiter, 1993]. Software help agents are discussed, such as Smalltalk Gurus which help with programming problems [Alpert, 1995].

12   Comparison of Interaction Styles (2.5%)

A popular scenario for testing involves users trying to achieve a problem-solving task by both 'command/language' and 'Direct Manipulation' interfaces, then comparing the results, e.g. [Jorg, 1993], [Benbasat, 1993] & [Bekker, 1995]. In these tests Direct Manipulation tends to give better results. However, Karl & Shneiderman show that when speech is used as an *extra* input channel (e.g. to directly activate menus, rather than by using the mouse) then the overall control bandwidth is increased [Karl, 1993].

Cohen [1993] advocates the use of audio cues in windowing systems to help users navigate complex data areas (also see Non-speech audio).

Gestural interpretation is discussed in *Parallel Use of Hand Gestures* [Bordegoni, 1994]. The different ways in which two hands can operate are identified. Parallel gestures can be *synergistic* (the meanings of each gesture is combined into a new meaning) or *concurrent* (two individual gestures happening at the same time).

Sellen & Buxton [1992] describe how a foot-pedal is used as an extra input for changing the 'mode' of text input from 'typing' to 'editing' without having to take the hands from the QWERTY keyboard.

Reflection and Goal Management [Trudel, 1995] discusses the ways in which users learn how to use button-type devices. They compare the following of instructions with what they call 'exploratory learning'. This is taken to mean that users identify their own *tasks* and order them sequentially to meet their *goals*.

Schar [1996] shows that command-based interfaces tend to trigger an 'explicit' learning mode which is rational, selective and involves focusing the conscious attention. Direct manipulation interfaces, on the other hand, tend to induce 'implicit' learning, where trial-and-error leads to the user understanding the relationship between variables. These issues are discussed more in Chapter 4 of this thesis.

13   VDUs and screens (1.9%)

Many papers are still published on the physical nature of visual displays, for example *VRT Luminance* [Saito, 1991]. Picking [1997] discusses the advantages and disadvantages of reading a musical score on a computer screen instead of paper.

14   Input / Output Devices (1.5%)

This topic has a relatively small coverage in the HCI literature. At first glance it might appear to be a relevant area for this thesis. However, on closer inspection the papers are concerned with the physical design of the interfaces, rather than the issues of what parameters they control. In this category comparisons are made between different physical input/output devices and new ones are proposed. Example papers are *Typing Speed Using a Stylus* [Sonkoreff, 1995] and *A Vision-Based 3D Mouse* [Nesi, 1996] which uses a camera to track hand-position in three dimensions.

15   Monitoring and Supervisory systems (1.3%)

Although the HCI issues in controlling complex machinery would seem to be a highly relevant area of study for this project, it transpires that most of the papers discuss knowledge-based support systems, which help the human operator in a complex environment by providing information. An example of this is the *Human Operator Support System* [Sussen, 1994] which aims to help human operators to diagnose faults in complex systems. It is pointed out that the stress of real situations could make this sort of system difficult to use, because stressful humans do not absorb new knowledge well!

A few papers discuss this issue further:

In *Trust, Self-Confidence & Automation* [Lee, 1994] there is a discussion regarding the way that humans in an automated pasteurisation plant tended to choose either 'fully manual control' *or* 'fully automatic'. Operators fail to successfully switch back to manual control once they rely on the automation.

> *"Designers should make special provision to allow users to operate under manual control -*
>
> *particularly in the early stages".*

Author: A D Hunt, Department of Electronics, University of York, UK, ca 1999

[Lee, 1994]

This theme is picked up in *Monitoring Behaviour & Automation* [Lin, 1993] where the term 'out of the loop unfamiliarity' is coined to describe what happens when humans become passive monitors. The system described is actually a supermarket computer system, but the idea is worth considering for all dynamically interactive control systems. Again Kontogiannis [1996] states, in relation to the control of nuclear power plants

"Training [people] to cope with emergencies becomes very important, especially with the

increasing levels of automation which leaves little scope for practising these types of skill".

[Kontogiannis, 1996]

Singh [1997] warns of the dangers of user 'complacency' in aviation systems. He notes that over 500 incidents of "crew over-reliance on automated systems" are highlighted in NASA's aviation safety reports.

16   Adaptive Interfaces (1.0%)

This area might sound relevant to this thesis, but it deals with interfaces that attempt to change in accordance with the user's current skill level. This is referred to as 'moving the goalposts'. There are areas where adaptive interfaces are required, but the control of real-time systems should perhaps involve *stable* interfaces that do not change. Musical instruments and vehicles are examples of systems where the *human operator* is the adaptive part of the system, whereas the object under control stays constant.

The topic of Adaptive Interfaces considers how the user interface should change as users progress from novice to expert. The emphasis is on changing the interface as and when the user progresses (e.g. *Matching Interface to User Skill* [Trumbly, 1993]). Some consideration is given to the definitions of the terms 'novice' and 'expert', for example *Defining the Novice User* [Fisher, 1992]. Gong [1995] describes an interface which changes its menu options according to how the user scores.

17   Virtual Environments (0.8%)

This literature has appeared since 1995 and details some of the many aspects of Virtual Reality. Witmer [1996] describes buildings which are 'mocked up' in virtual form so that personnel can find their way around even though the building is not yet in existence. Paulos [1997] explains how we are hampered by the lack of a body in cyberspace, and suggests how we might use robots to re-establish our physical presence in a remote location!

Burden [1996] reviews the contemporary technology for VR and suggests that the feeling of immersion will increase if tactile and force feedback systems are used. He also emphasises the need for 3D audio. He concentrates on the number of different sensors that can be used, rather than the style of interaction.

18   Time-Critical Systems (0.7%)

A good example of a time-critical system is an interactive computer game. Given the number of such systems present in the world it is astonishing that only two papers in this survey even refer to computer games!

Ben Shneiderman's original definition of Direct Manipulation was inspired by watching people play games with active and continuous involvement. The 'fun' side of such user engagement is discussed in *Usefulness, Fun and PCs* [Igbaria, 1994]. They deduce that while the purchase of technology by businesses is primarily driven by perceived 'usefulness', the acceptance of the technology by people actually working with it is often driven by perceived 'fun'.

Scown appeals to the HCI world to look beyond office-based task. In *HCI and Multi-Agent Real-Time Systems* [Scown, 1992] he suggests that flight and plant control are examples of real-time systems which are currently being overlooked. His argument is that since most HCI tests are carried out on single-user office-based tasks such as word-processors there is a wealth of parameters which are *not* being measured. These are identified as:

- multi-person interaction in a complex system,
- real-time issues (particularly those of a 'control' nature),
- continuous changes in parameters,
- lack of state replicability (i.e. complex real-time systems cannot simply return to the last 'well-known state', instead the system needs 'steering' through a complex parameter space).
- the cost of making a mistake (not all control systems have an 'undo' button!).

Author: A D Hunt, Department of Electronics, University of York, UK, ca 1999

Other time-critical systems include air-traffic control. This is a highly complex, safety-critical multi-person job and several papers looks at specific tasks, e.g. *The Role of Flight Progress Strips in Air Traffic Control* [Edwards, 1995].

19   Non-speech audio (0.6%)

Several authors consider the use of 'earcons' (non-speech sounds) as an effective way of giving interactive feedback to the user. Brewster [1995] shows that humans are able to process different sounds in parallel, while Jacko [1996] studies the age that children begin to respond to auditory cues in software.

Rauterberg [1998] explains how sonic alarms are designed to be distinct. In doing so he explains the essential difference between audio and vision.

> *"The eye is a directed sense and focuses attention, the ear is an all-round sense . . and guides*
>
> *the visual attention . . Humans cannot close their ears in the same way that they close their eyes*
>
> *. . therefore auditory devices are generally preferred to visual signals as warning indicators".*

[Rauterberg 1998]

Vertegaal [1996] describes an experiment to compare mouse, joystick and PowerGlove for controlling a sound's timbre. He states that:

> *"though it is clear that a direct correlation between gesture and sound reduces cognitive*
>
> *processing load and enhances performance . . . this impairs the use of the system as a generic*
>
> *sound synthesis control".*

[Vertegaal 1996]

Chapter 3 of Hunt's thesis gives more details about the human-computer interface in music systems and Vertegaal's work is covered there too. Vertegaal also describes that:

> *"certain parameters of a task are perceived as being integrally related to one another . . . while*
>
> *others are separably related . . . Consequently users manipulate certain parameters*
>
> *simultaneously (such as the x and y position of a graphical object).*

[ibid]

He concludes that the mouse and joystick give better performance at the timbre exercise than the glove, but that most of his subjects were familiar with the mouse. He also notes, regarding the mouse and the joystick, that he would not *"expect the musician to use these as a musical instrument"*.

20   HCI Research Issues (0.6%)

Not surprisingly perhaps, the topics covered in this category tend to be those which are *already* receiving the greatest coverage in the literature. Particular focus appears to be given to CSCW and CMC which are summarised in category 'Computer Mediated Communication'.

The following authors talk about wider issues:

Keeler and Denning [1991] challenge the accepted notion of HCI communication theory. They emphasise the importance of what they call 'the user's engagement with objects' i.e. the task is so engaging that the interface becomes 'transparent'. They contrast this feeling of 'involvement with objects' with the conventional notion that the human communicates with an intermediary system (the computer) which then goes and does the work, thus giving the user a '3rd-party' experience.

It is interesting to note that DeGreene [1991] uses the terms 'analystic' and 'holistic' to describe respectively the formal approach of mainstream HCI design and the more dynamic 'ergonomics' approach. He implies that much of HCI design is too reductionist and analytical and that much more needs to be done to include the users (who are the real experts) as they are involved in intimate day-to-day operation.

Jacob et al give a good HCI research overview in *Interaction Styles and I/O devices* [Jacob, 1993]. They identify a series of research directions which include developing new input devices and pursuing further study of different interaction styles. Their paper suggests the following categories requiring further work:

• The 'next' interaction style. This is not fully defined but is based on moving away from the 'command-issuing' paradigm and concentrating more on 'sensing' the user's body. This will result in less verbal information transfer and more real-time control.

Author: A D Hunt, Department of Electronics, University of York, UK, ca 1999

- Interface Devices: 3-D pointing and manipulation, gesture abstraction, simultaneous two-handed input, stereo image displays, virtual input devices, speech, eye-input technology and directional audio.
- Ergonomic considerations: adaptations for disabled users, computer sensing of operator position in the room, better graphics resolution over a much larger area, force and tactile feedback, environmental controls, etc.
- Methods for data manipulation and visualisation: non-speech audio for data 'display', touchable 3-D displays, techniques for representing high-dimensional data, and even smell as a way of portraying data!

The authors of *Approaches to Interface Design* [Wallace, 1993] focus on 'ease of use' and refer again to Ted Nelson's often cited comment:

> *"Any system which cannot be well taught to a layman in ten minutes, by a tutor in the presence*
>
> *of a responding set-up, is too complicated".*

[Nelson, 1987]

However, musical instruments have existed for thousands of years, and it is a rare experience to find one that takes less than ten minutes to teach!

21 Robots & Automated Manufacturing (0.4%)

This category concerns human interaction with mechanised processes (e.g. robots and computer integrated manufacture). This topic receives much greater coverage in non-HCI journals. An example paper is *Actions Representation in 4D Space* [Adorni, 1991] which discusses issues of moving parts and how to automatically control them over time.

22 Tactile Interfaces (0.2%)

This final category concerns systems that allow humans a sense of touch or force-feedback in the interface. It is not directly concerned with the issues of interface parameters and dynamic control, but it may play a part in future work which arises from this thesis.

Akamatsu [1996] considers the use of a mouse with and without force feedback. He records how 'error rate' is affected when such feedback is used in 'targeting' tasks. Gobel [1995] outlines a simliar task and concludes that standard 'tracking' tasks are worsened by force-feedback, but that 'ballistic' movements are improved.

23 Miscellaneous (1.5%)

This category holds those references which do not talk about systems or humans or the interaction between them. Topics include the dissemination of information about HCI and curriculum development for HCI courses e.g. [Preece, 1991]. Other papers include *It's Not Really Theft* [Sealce, 1998] - a discussion about the reasons for software piracy!

Summary of HCI Literature

This survey shows that the predominant categories that are discussed under the umbrella term HCI are:
- Knowledge Based Systems and Data access.
- Design Theory & Software Engineering.
- Language-based interfaces & Hypermedia.
- Computer-Mediated Communication.
- Social, Cultural and Health implications of computers.
- User interface testing and modelling.
- Menus, icons & graphics.

Nearly three quarters of the literature concentrates on these topics. In contrast, less than 6% of the literature addresses topic areas which might be considered relevant too. On closer inspection, less than 1% of the HCI literature is calling for the community to re-think its priorities in terms of humans controlling complex real-time systems with a greater degree of engagement. This is not to say that the majority of HCI research is misdirected, but rather to point out that there is most definitely scope for further study in this area.

Author: A D Hunt, Department of Electronics, University of York, UK, ca 1999