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DESIGN 2006

DISCOVERY IN DESIGN: DEVELOPING A PEOPLE - CENTRED COMPUTATIONAL APPROACH

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1. Introduction

This mainly speculative paper describes the activities of the Discovery in Design (DiD): People-centred Computational Issues (DiD) Cluster which has been established under the UK AHRC and EPSRC 'Design for the 21st Century' Initiative (D21C). The objectives of this initiative are to promote the formation of new communities of design researchers, practitioners and end users and to build a common reference framework re theoretical concepts, cultures languages and methods. The intention is that this will stimulate new ways of design thinking that will meet the challenges of 21st century society (www.design21.dundee.ac.uk).The objective of the Discovery in Design: People-centred Computational Issues Cluster (www.ip-cc.org.uk/did) has been to identify primary research aspects concerning the development of people-centred computational design environments that engender concept and knowledge discovery across diverse disciplines and domains. Such systems would represent a new approach to the establishment of generic computational support for conceptual design relating to many disciplines.Current computer-aided design and decision support tools support the later, well defined stages of design where a product or objective is physical, tangible, and comprehensible. However, more abstract concept formulation and development is poorly supported, especially where uncertainty is an inherent characteristic. Furthermore, computer-aided design and decision-support tends to be domain specific. There is little or no exploitation of cross-domain experience. Research and development agendas that have the potential to redress both these imbalances are required. The Cluster has investigated the utility of established and emerging computational intelligence, enabling computational technologies and people-centred issues across a diverse set of problem domains relating to widely differing disciplines to not only identify synergies, but also to separate and distill peculiarities. Collaborations across engineering, drug design, software engineering, biosensors and material design and graphical and media product design have provided a basis for study. Cluster membership has ensured specific expertise in each of these areas with some members active across several. Views and approaches from practitioners and researchers that are not normally considered in the same time-frame and context have thus been investigated. The strength of the Cluster has therefore been in the collaboration of seemingly disparate cognitive disciplines that require a common core expertise to support decision-making processes. The result has been the initial identification of primary aspects relating to mutually symbiotic design environments that create new potential interfaces for capturing and enabling discovery and innovation.

2. Why People-centred?

During the early stages of design and decision-making, people play the major common role processing both qualitative and quantitative criteria in a manner that they may find difficult to articulate. Inherent uncertainty and poor problem definition initially exacerbate the situation. Preliminary machine-based problem representations may comprise fuzzy concepts and sparse information. Further, representations change as information and knowledge accumulates from initial search and exploration and associated human assimilation. It is this complex, dynamic environment that engenders the discovery of new, sometimes seemingly unrelated information which can lead to innovative and creative solutions to problems.

Human experience plays a major role in terms of meaningful evaluation of data and the introduction of external information. People-centred systems are required that meld such knowledge with machine-based simulation, search and exploration, data processing and visualization. The decision-maker should become immersed in the system playing a major role in an iterative process of data generation; evaluation and analysis; subsequent design space reformulation and further exploration of the redefined space. Such an interactive environment may lead to the capture of experiential and tacit knowledge within this iterative reformulation process [Goel, 1997; Parmee 2002, 2004].

The Cluster's activities have concerned the identification of people-centred issues relating to computational aspects that include design representation and simulation; evolutionary design space search and exploration; data mining and processing; computationally intelligent systems; machine-based enabling and bridging technologies and information visualization and presentation.

Complementary investigation of areas of human-computer interaction and cognitive aspects have included assimilation of information relating to multi-variate, multi-criteria and constraint relationships; knowledge extraction and knowledge capture; subjective solution evaluation; implicit learning and generation of tacit knowledge; stimulating innovative and creative thinking.

3. Core Cluster Workshops

At the time of writing the Cluster has hosted four, two-day Workshops comprising presentations from industry and academe with associated round-table discussion and sub-group working to address both global and specific issues. Thus the complex characteristics of each design domain; their people-centred aspects and computational strategies are being identified along with generic aspects and specific peculiarities. Typically, attendance at each Workshop has comprised delegates from civil, mechanical and aerospace engineering, biotechnology and the pharmaceutical industry, software and communication engineering, computer science, media product design, psychology, human factors and human/computer interaction. Most delegates have been largely unaware of the extensive body of existing design research although some members have been active in their particular areas e.g. engineering, product, media design and associated human factors. For some, the Workshops represented an opportunity to position and understand their design activities within a more global context in terms of associated research. There follows brief descriptions of the presentations and Workshop activities that have provided a wealth of information. Three scribes attended each Workshop with the specific task of recording all interim discussion and comments.

3.1 Workshop One

The main objective of Workshop 1 was to establish a common language and a mutual understanding of the diverse concepts relating to both design discovery and people-centered computation. This was achieved via an initial overview of the Cluster's objectives and planned activities presented by Ian Parmee followed by short presentations from each of the delegates present. Extensive interim discussion and debate highlighted problems relating to both differing terminologies and requirements across the Cluster's diverse design processes. The mix of disciplines represented at the Workshop ensured much initial confusion which rapidly diminished as the first day progressed and an overall better understanding of each other's domains and vocabularies emerged. The final task of day one was for each delegate to list issues that had arisen during the day that s/he felt were primary aspects in terms of people-centred computation and knowledge / design discovery. Analysis of these aspects revealed a high degree of commonality indicating that the Cluster as a whole was already understanding primary generic issues. Four major aspects were identified for break-out sessions during day two relating largely to the requirements of an envisaged user-centred computational design environment:

1. **Two-way knowledge capture** e.g. on-line integration of user knowledge and experience; utilisation of knowledge extracted from the system to facilitate user innovation and creativity;
2. **Overall type of user interaction** e.g. issues relating to scale and discipline; single- or multi-user; transparency across design teams;
3. **Usability:** e.g. must be engaging and exciting - particularly important with young designers; seamlessly supports both individual and team-working; must allow freedom of activity;
4. **Exploration** e.g. supports exploration outside of pre-conceived bounds; traceability – need to know where we have been and why.

These provided topic areas on day two for the break-out groups which comprised a balanced mix of academic and industrial members from differing disciplines. Subsequent presentations from each group revealed a diverse set of approaches to the task and a wealth of further ideas, concepts and information. By the end of the Workshop it was apparent that a general understanding of cross-disciplinary concepts had been developed and that we were all beginning to better understand at least the basic requirements of a generic people-centred computational environment for conceptual design.
The initial overview and most of the short presentations can be found on the DiD website.

3.2 Workshop Two

The first Workshop established a reasonable level of general understanding with regard to differing terminology, requirements of the differing disciplines and the technologies available to us. The intention of the Second Workshop was to concurrently investigate, at a greater depth, the softer, human-centred aspects of our aims and objectives and more detailed descriptions of the problems facing us in terms of engineering, product, software, drug and sensor design. The format of the second Workshop comprised invited presentations from external speakers and from Cluster members with extended discussion sessions at frequent intervals.

The initial speaker, **Pat Jordan** of the Contemporary Trends Institute, focused on lifestyle trends and how they relate to technology and innovation. He defined what we mean by trends and how they represent the spirit of the times in terms of behaviours, attitudes and lifestyles. They can be ascertained through 'valves' of popular culture e.g. television, film, media and politics and how their anatomy is defined by their make-up and source. These aspects were illustrated via several current examples.

Creativity was addressed by **Ian Jones** of Cardiff University. To be creative we may have to work against our training. People may become increasingly creatively redundant as they become more specialised. Perhaps to be creative the designer has to be allowed to explore seemingly nonsensical solutions. Is it possible for the computer itself to learn nonsense potential and present the user with simple concepts that stimulate creative thinking? Ian's presentation of many such interesting concepts provoked much discussion relating to possible machine-based support for creative thinking.

Chris Simons of UWE, Bristol, discussed the complexities of the software design process. Software is an abstract entity and so difficult to design and specify. As a result, promoting a shared understanding of software design across teams is difficult. A major thrust of current software design research is aimed at predicting software development costs; research addressing design support tools is less readily evident. Software design patterns are emerging but solve only part of the design problem [Simons et al, 2003]. Could an automated search process help? Indeed, is quantifying the software solution search space possible?

The weaknesses of early application of expert systems in civil engineering deisgn were discussed by **John Miles** of Cardiff University before he moved on to current applications of evolutionary computing where there is a need to introduce other coputational techniques to support its integration with design processes [Shaw et al, 2004]. The designer needs to be supported rather than replaced in such systems utilising common sense, expertise and personal preferences. Spatial reasoning and problem representation are major issues requiring further research.

The second day commenced with **Chris Jofeh** of the Ove Arup Partnership who addressed issues faced by designers in the industry. Currently Ove Arup use crowd models and simulation in design. Their in-house 'Real-time' system provides prior simulation of towns and buildings. This is at a level of detail such that virtual walkthroughs with wheelchairs or simulated visual impairment can identify requirements re access and lighting. Presentation of information is a primary concern and tools are required that collate and appropriately present such information..

Computational intelligence techniques for the pharmaceutical and biotechnology domains were discussed by **Ian Parmee**, Bristol UWE, and **Lisa Hall** of Cambridge University. Resulting systems utilise evolutionary computing (EC), data-mining and visualisation techniques to extract design information and capture designer knowledge. EC techniques developed for engineering design have been modified to provide efficient search across the complex combinatorial chemical space of reagent libraries to discover druglike compounds. User interaction is essential to capture tacit knowledge fom the chemist and for subjective judgement within multi-objective evolutionary processes operating within poorly defined problem spaces where uncertainty is prevalent. The potential integration with sensor design entails concurrent search of chemical space and engineering space to design the chemical reactant and the instrument in which the detection takes place.

The final presentation by **Jan Noyes,** University of Bristol concentrated upon human factors. With user-centred design humans are increasingly the bottle-neck in the system. Although technology is advancing, human physiology is not. Over-automation and removing the human from the loop tends to result in failure.. However, automate too little and the benefits of a complex system remain unutilised. We need to identify optimal human-machine interaction and design according to the skills and weaknesses of people [Noyes, 2001].

Ample time was allowed between the presentations for questions and resulting discussion over the two day period. At the end of the presentations on each day each delegate was asked to identify what they considered to be three main issues from the previous talks. A round table discussion regarding these issues was then led by members of the core team. A similar exercise took place in the second half of day two. All aspects were listed via flip chart during these discussions and each day ended with a summary of the primary items that had emerged during the day.

The presentations in Workshop Two were particularly diverse and wide ranging which resulted in a considerable number of primary items plus many comments and observations. All of these were noted and collated by the Workshop scribes for further analysis during Workshops 3 and 4. Presentations form the workshop can be found on the DiD website.

3.3 Workshop Three

The intention of the third Workshop was to identify:

- stages and / or aspects of the design process that have proved difficult to support computationally;
- gains and losses through attempting to formalise design via specific computational tools;
- our 'wish list' for future computer-aided design systems
- what, with appropriate research agendas, would be possible in the short, medium and long term fully taking into consideration the outputs from Workshops one and two?

We had some excellent speakers with extensive experience of designing with no computational support or with varying degrees of support across product, media, scientific and de novo drug design. The intention was again to achieve our objectives via discussion and break-out sessions based upon the presented and previously collated material.

Our first speaker was **Tom Karen**, former director for Ogle Design and designer of several UK design icons including the Reliant Scimitar GTE (1968), the 3 wheeled Bond Bug (1970) and the Raleigh chopper bycicle (1970). He described himself as an intuitive designer with an irrepressible desire to improve things, always storing information away regarding possible opportunities for improvement. He has a 'butterfly mind' that jumps from one observation to another always attempting to map observed good design onto other, less successful examples. Form is very important to him hence a preference for working with students with good drawing skills. In terms of functionality you should put yourself "in the skin of the user" considering their needs and values. If you wait for guidance from the user you will never be innovative as customers base their ideas on what they know. People generally don't like new ideas.

David Smith of the University of Wales discussed issues relating to the design of human-centred information systems. Language problems relating to specification cause problems and differing languages are required depending upon design area and current trends. The 'language of now' is difficult to evaluate. Current design process may not be concerned with the physical.. Who could have predicted the virtual products that are now much in evidence? Designers should think in terms of human purpose rather than business. Context should be viewed in terms of human activity.

With regard to scientific design **Simeon Barber** of the Open University Planetary and Space Sciences Research Institute opened day two with an in-depth look at the Beagle 2 Mars Lander design process. Many differing organizations were involved. An interdisciplinary team covering science and engineering had significant problems transferring tacit knowledge at the conceptual stage. Written specifications couldn't sufficiently capture all knowledge. Block diagrams and flow diagrams were far more useful. It was still necessary to blur boundaries between science and engineering. Co-locating team members supported tacit knowledge transfer and increased design process efficiency. Model makers proved very useful in realizing their ideas and concepts.

A detailed presentation relating to drugs followed with **Paul Mortenson** of Evotec OAI describing objectives and processes relating to their design. Drugs must target a specific protein in the body. The search space of potential drug molecules is estimated at 10^{60}. A very small fraction needs to be identified. Selectivity is often a problem e.g. the drug should not bind to other proteins; an appropriate rate of metabolism is essential etc. Potential design solutions can be identified manually, with computational assistance or via automated computational design. Manual design introduces an element of bias based on users past experience whereas automation limits design to implementation / strategic issues as there is no guarantee the chemical can be made afterwards. Both limit opportunities for creative thinking. Manual design with some computational assistance seems the best way forward. However, it is also essential to improve the quality of predictive models.

Considerable interim discussions took place during these presentations. Again, at appropriate points, delegates were requested to draw out aspects from the Workshops that they considered to be of prime value and all aspects were listed via flip chart and thoroughly discussed It became apparent, even in day one, that the group's ideas, concepts and understanding were beginning to converge as aspects that had first arisen during the highly diverse Workshop two were reappearing, perhaps in a slightly different form, in Workshop three. We were beginning to reach concensus. It was very tempting at this point to disturb this concensus and to explore futher but given the overall objectives of the Cluster in terms of the D24C initiative (i.e. to identify primary research issues for the initial call for funding) and the time left to realize these objectives it was decided to concentrate on what we had thus achieved.

By the end of the Workshop three we had identified and agreed upon five primary issues that required concurrent and significant research effort if a generic people-centred computational environment for conceptual design is to be achieved. The five issues are:

1. Knowledge Extraction / Knowledge Capture;
2. Search and Exploration;
3. Enabling Environment;
4. Representation;
5. Understanding humans.

3.4 Workshop Four

Workshop four was considered a 'focusing Workshop'. A mass of information had been gathered during previous activities and this information required further collation, analysis and classification in terms of the five identified key issues. It was also very necessary to review all that had taken place to refresh cluster members' memories. The fist task prior to the Workshop had been to identify classes for the 350 comments, ideas and issues that had emerged and been collated from the previous three Workshops. This resulted in the identification of thirty-nine classes, a complete list of which can be found at www.ip-cc.org.uk/Did and following the 'Workshops' menu.

It was now necessary as a group activity to assess how these classifications relate to the five key issues identified in Workshop three. In order to do this ten two-dimensional graphs comprising the constituent couplets of the five key issues were generated (e.g. 1-2, 1-3, 1-4, 1-5, 2-3, 2-4, 2-5, 3-4, 3-5, 4-5). Increasing relevance of the classes were represented on each axis as shown in the 'Search and Exploration' / Understanding humans' couplet of figure 1.

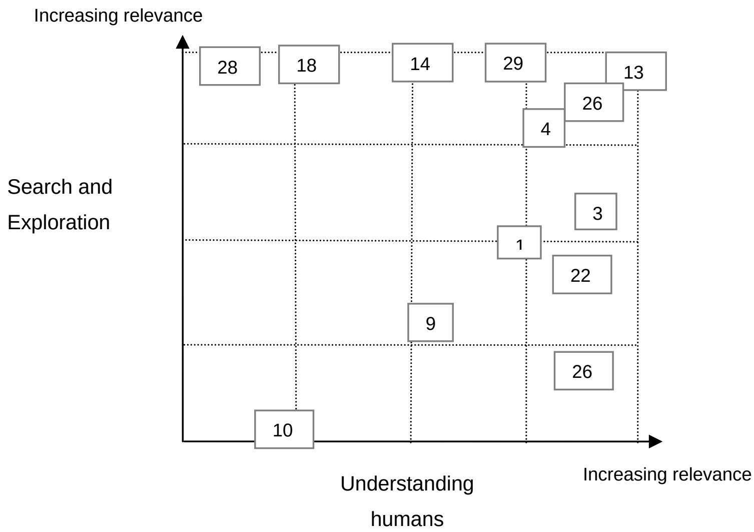

Figure 1. Two-dimensional slice of the five key issues

Table 1. Examples from the thirty-nine classes plus some of their component ideas / comments

1.	**Learning** e.g support of implicit / subconscious learning; learning from nature; discovery and insight; multiple uses – teaching tool?,
3.	**Capturing/Extracting/Obtaining knowledge** e.g. qualitative and tacit knowledge; user experience; formalising designer's internal model; mapping tacit knowledge; capturing disparate sources and types of knowledge
4.	**User Support** e.g. generating hypotheses – induction**;** pattern recognition – GOOGLE Vs Amazon model; questioning element; focus / diversify in response to user action; software agency- based guides that contradict, prompt, confuse?
13.	**Creativity & Innovation:** Thinking nonsense breaks down historical / cultural barriers; creativity by contradiction; machine-based questioning of user hypotheses/assumptions; modeless software - butterfly mind?; can you search the unknown?
10.	**Re-use / Deconstruction / Ecology** eg design for consumption / ecology; Un-design environment- deconstruction; re-use and improve
26.	**Modelling** e.g. Machine-based tool to assist people to describe their model; Constant, cyclic modification of model; information transfer from abstract to definable; holistic versus modular; Intangible/tangible → transparent (how can the machine help us)?

The ten 2D graphics were distributed around three sub-groups who were requested to discuss and then place the numbered classes in the most appropriate positions. Only a sample of the positioning of the thirty-nine classes has been shown in figure one to ensure clarity. The intention was to provide a visual aid during discussions in terms of the relative importance of the various classes relating to the five key areas. Examples of the classes along with samples of their component comments, ideas and issues are given in Table 1.

The exercise went very well both in terms of providing a visual representation (as can be seen from the photograph in figure 2) and causing all delegates to re-think and discuss the relevance of much of our previous activities.

This processing, presentation and further discussion supported the delegates in the preliminary identification of the main factors relating to each of the five key issues. Further analysis of the collated information is currently underway to confirm our preliminary findings and the results of this analysis will be available within four Workshop reports which will be published in 2006. In the interim, we can simply extract those classes that lie in the upper quartiles of the four instances of each Key Issue evident across the ten charts. By then selecting those classes in this sub-set that occur most frequently, it is possible, at this stage to identify the classes that could be considered most relevant and that likely represent primary areas of research relating to the identified Key Issues. Results from this preliminary analysis are shown in table 2.

Figure 2. Display of the 2D representations of the Five Key Issuesand thirty-nine classes

Table 2: Classification of key issues in terms of the five identified research areas

Knowledge Ext & Cap	Search & Explore	Enabling Environs	Representation	Understanding Humans
Co-operation and collaboration; Capturing/ Extracting knowledge; Enabling Computational Technologies; Emergence; History and Traceability; Modelling; Data Issues; Creativity and Innovation; User support; Learning.	User support; Creativity and Innovation; Modelling; Emergence; History and Traceability; Capturing/ Extracting Knowledge; Data Issues.	User-centric Issues; Co-operation and Collaboration; Useability; User Interface; Creativity and Innovation; Multi-users and Multi-user Interaction; Capturing / Extracting Knowledge; User support; User interaction.	Visualisation / Senses Stimulation; Form; Modelling; Capturing / Extracting Knowledge; C-operation and collaboration.	Usability; Visualisation / Senses Stimulation; User Interaction; Validation and Risk; Multi-users and Multi-user Interaction; Creativity and Innovation; Interface; User-centric Issues; User Support; End User Issues; Learning; Form; Co-operation and Collaboration.

4. Discussion, Future Plans and Conclusions

One of the main outcomes of the cluster activities has been a very significant increase in awareness across the members and their particular disciplines of design issues relating to many differing forms and levels of complexity. It is generally agreed across the membership that each discipline has come away with new knowledge that is of benefit to their reseach and / or current practice. The Workshops have been extremely information-rich which, although very stimulating, has caused problems in terms of achieving convergence and generating meaningful output. It is likely that a significant proportion of the generated knowledge is tacit and will requires more ‘teasing-out’ through further interactive sessions.

This putting together of such a diverse set of disciplines with varied backgrounds over a nine-month period with a heavy schedule of Workshops and interim activities specifically to discuss such design, computational and people-centred relationships is probably unique. There is no doubt that, with hindsight, we would have organised our activities a little differently but the outcomes have been entirely satisfactory in terms of the objectives both of the cluster and the D21C Initiative. However, the overall benefits in terms of a learning exercise and an opportunity to move closer to the establishment of people-centred conceptual design environments are far greater. In the light of this and to ensure that the momentum from this initial activity is not lost we are establishing a virtual 'Institute for People-centred Computation'. The initial objectives of the Institute are, through close multi-disciplinary working involving both academe and the industrial / commercial sectors, to develop agendas for research and development that will result in user-centric computational environments that will, for example:

- support human / machine-based information discovery that will lead to innovative and creative solutions beyond those typically produced by decision-makers alone or by decision-makers supported by current computational systems;
- through human interaction reduce uncertainty and associated risk during the early stages of design and decision-making processes;
- capture experiential and tacit knowledge whilst supporting implicit learning and an improved understanding of complex problem relationships.

The intention is also to support Workshops, Seminars, Special Interest Groups, Summer Schools and Training Events. These will ensure a better understanding of the domain and the requirements, both human and machine-based, of the perceived people-centred computational environments whilst also disseminating new knowledge to those involved in their development and utilization. The long term aim is to develop collaborative multi-disciplinary proposals for research and development and subsequently implement programs that will ultimately deliver generic commercial systems.
Further information can be found at www.ip-cc.org.uk.

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