From Gaia to HCI: On Multi-disciplinary Design and Co-adaptation

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In 1979, James Lovelock published a controversial book entitled *Gaia: A New look at Life on Earth*, which challenged the conventional wisdom about how the earth evolved. He hypothesized that living organisms form a self-regulating system, named after the Greek Goddess *Gaia*, which is directly responsible for creating and maintaining the earth's atmosphere. In other words, life did not simply evolve in response to pre-existing physical conditions but rather *co-evolved*, regulating the earth's physical conditions to create a homeostatic balance that has been maintained for eons. Although initially trained in chemistry, Lovelock worked outside and across the boundaries of 'normal' science. He became a successful inventor of high-precision scientific instruments; his *electron capture detector* contributed to key discoveries including the pervasive role of pesticides in the environment. It was in his capacity as an inventor that he was hired by NASA to develop instruments to analyze extra-terrestial atmospheres and to address the question of whether or not there is life on Mars.

What, you might well ask, has this to do with human-computer interaction? For me, it is a story of the essential role of interdisciplinary research: how reaching across disciplines is essential for understanding certain kinds of phenomena and how sharing a common goal unites people across disciplinary boundaries. More specifically, it is about co-evolution, but on a human scale. My doctoral dissertation, *Users and Customizable Software: A Co-adaptive Phenomenon* (Mackay, 1990) is directly linked to the concept of co-evolution and provides an explicit framework for studying and both showing how technology influences the people who use it, and how they in turn re-interpret it and adapt it in ways never envisioned by the original designers. To understand and create explicitly co-adaptive systems requires expertise from multiple disciplines and is, I believe, essential for HCI as a field.

I first read *Gaia* in 1982, when I was a manager at Digital Equipment Corporation. I had written an authoring language that enabled non-technical users to create educational software with text, graphics and high-quality digital video from a videodisc. We simultaneously released IVIS, the first commercial interactive system with integrated text, graphics and video, and then produced over 30 educational software products. This was an extraordinary time and we were excited by the wealth of possibilities offered by IVIS, although I remember being severely questioned by a vice president who simply could not believe there was a market for “watching television on a computer”.

One of my roles as manager was to present IVIS to potential customers, including NCAR, the National Center for Atmospheric Research, in Boulder, Colorado. They had vast quantities of multi-media climate data from around the world and hoped IVIS could help them store and visualize their data. Having just read *Gaia*, I was surprised to see it mentioned in their annual report as a driving factor behind several important discoveries. I knew that Gaia had been dismissed by main-stream biologists, yet here were prestigious scientists at NCAR who relied upon it. Why?

A key factor was that these scientists shared a common research question, to understand and predict the weather, that required them to work across scientific boundaries. Their inclusion of biologists in a domain previously dominated by physicists and chemists led them to fundamental insights about the impact of living organisms on the atmosphere. For example, existing physical models could not explain 20% of the methane in the atmosphere; their biologists traced it to huge termite mounds in South America!

I was struck by two observations: first, these scientists viewed working across disciplinary boundaries as essential for success. Like Lovelock, who teamed up with the biologist Lynn Margulies, they found that certain kinds of questions could only be addressed though shared perspectives; dogmatic focus on one discipline simply would not work. This resonated with my beliefs about software development. At that time, virtually all interactive software was developed by people trained in engineering or math; professional organizations such as SIGCHI did not yet exist, nor were there degree programs in human-computer interaction.

I was in transition at that time; I decided to stop running a large production group and return to research on the next generation of multi-media software. Already an anomaly at DEC with my training as an experimental psychologist, I realized that even a mix of psychology and computer science was not enough. Inspired partly by Lovelock and the scientists at NCAR, I created an explicitly multi-disciplinary research group, with one third programmers, one third psychologists and social scientists, and rest a mix of designers, including a typographer, a video producer and even an architect. We also actively included users, treating them as members of the design group throughout the design process, an early example of participatory design.

I will not pretend that it was always easy: we often had major arguments over design process, evaluation criteria and the ultimate design. Yet we were united in a common goal, believing sincerely that multi-media computing would change the world. We forced ourselves to articulate our underlying assumptions, to respect each others' perspectives and contributions, and to come to a shared understanding.

Multi-disciplinary design is now common (or at least, given lip service) in HCI. But in those early days, seeing how multi-disciplinary research helped legitimize the Gaia hypothesis at NCAR profoundly affected my own research, not just enforcing my belief in multi-disciplinary teams but also encouraging me to study multi-disciplinary design as a subject in itself. I continue to be fascinated by the multi-disciplinary design process and how best to benefit from the insights gained across disciplines. I always work with multi-disciplinary research groups and have drawn from these experiences to develop new design techniques (see Beaudouin-Lafon & Mackay, 2002 and Mackay, 2002).

My second insight relates to a fundamental concept in the book, that of co-evolution. I had been fascinated by how our customers at Digital reinvented the technology we developed, often in unexpected ways. Nardi & Miller (1991) describe a similar phenomenon among spreadsheet users and communication technologies have often been reinvented, from email to SMS and instant messaging. (I remain surprised how often software manufacturers ignore this phenomenon, since user-driven innovation is an inexpensive source of pre-tested products.)

My doctoral dissertation explored how users actively adapt as well as adapt to the technology they use. I chose the term *co-adaptation* to differentiate it from *co-evolution*, a biological process involving changes in both DNA and the environment. Although it operates on much smaller time scale and through different mechanisms, co-adaptation is deeply influenced by the concept of co-evolution. I discovered several naturally occurring examples of co-adaptation during a two-year study of email use in a large corporation and in a five-month study of user customization.

In the first study, users re-invented a mail-filtering system we had introduced: they twice completely redefined it and significantly increased its adoption by others in the organization. In the second study, some users were completely overwhelmed by each new software version and were forced to completely adapt their behavior to accommodate it, while others painstakingly retrofitted and adapted the new version so it performed like the old. Every group informally designated one person who created and collected useful customizations and shared them within the group. Both studies found individual and social co-adaptation: users all adapted their behavior in response to technical and social constraints, and a few also actively adapted and shared their innovations with others.

Knowing that co-adaptation occurs, the interesting question for HCI is what are the implications for design? Unfortunately, while Gaia provided the initial insights, it does not tell us *how* to create successful co-adaptive systems. Although multi-disciplinary, the Gaia hypothesis remains squarely within the natural sciences, whose goal is to explain *existing* natural phenomena with theory and empirical evidence. Designing novel interactive systems clearly benefits from scientific disciplines, but also requires design and engineering expertise, and even that may not suffice.

So just how do we enable users to change and adapt their software in productive ways, without introducing more problems than we solve? One possibility is to lower the barriers to customization, through end-user programming (Lieberman et al., 2005) and tailoring. I have been exploring a different angle, in the context of mixed reality systems. Physical objects, particularly paper, can act both as an interface to a computer as well as objects in their own right. For example, we studied how air traffic controllers appropriated paper flight strips (Mackay, 2000) which provided the insights necessary to create a highly appropriable mixed reality system called Caméléon (Mackay et al., 1998). By augmenting the physical flight strips, controllers retained their familiar functions and flexibility, but were also able to access RADAR and other on-line systems and also communicate with other controllers. Caméléon's 'interaction browser' was designed to let controllers choose how their actions on these augmented strips were linked to other on-line systems and to permit them to develop new uses that we did not anticipate. Taking advantage of an existing, easily appropriable paper-based interface led us to create an interactive system that maintained the simplicity and adaptivity of the physical strips while gaining increased power through access to on-line systems and communication with other controllers.

Together with Michel Beaudouin-Lafon, I have also been exploring *generative theory* (Beaudouin-Lafon & Mackay, 2000) which provides design principles for designing and integrating interaction techniques. We view interaction as a phenomenon in its own right, to be designed and modified by both designers and users. For example, the principle of *reification* turns users' previous interactions into concrete objects that they can visualize, modify and share. Ideally, this creates a Gaia-like feedback loop whereby users can reflect upon their past experience and reuse, modify or borrow successful adaptations. In some cases, such reflection may even lead to redefining the system itself.

In re-reading Lovelock's book, I thought back to the early days of HCI, when everything was new and we could draw from a wide variety of disciplines to inspire us. Over 25 years later, the Gaia hypothesis is taken seriously in scientific and environmental circles, multi-disciplinary design has become the norm in many corporations and HCI researchers now recognize the importance of socio-technical systems (Suchman, 1987). The concept of co-evolution (if not co-adaptation!) has started to appear in the HCI literature and I believe that the design of co-adaptive systems will soon be a focus of HCI research.

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