Journal of Scientific and Practical Computing
Vol. 1, No. 2 (2007) 67–69
Noted Reviews

COMPUTATIONAL THINKING IS PERVASIVE

ALAN BUNDY

School of Informatics, University of Edinburgh, U.K.

1. Introduction

A remarkable intellectual revolution is happening all around us, but few people are remarking on it. Computational thinking is influencing research in nearly all disciplines, both in the sciences and the humanities. Researchers are using computational metaphors to enrich theories as diverse as protoeomics and the mind-body problem. Computing has enabled researchers to ask new kinds of questions and to accept new kinds of answers, for instance, questions that require the processing of huge amounts of data.

Of course, we all have computers on our desks nowadays. We all use them for email, web browsing, word processing, game playing, etc. But the computational thinking revolution goes much deeper than that; it is changing the way we *think*. Computational concepts provide a new language for describing hypotheses and theories. Computers provide an extension to our cognitive faculties. If you want to understand the *21st* Century then you must first understand computation.

At the University of Edinburgh, we have been exploring these themes in a series of seminars (http://www.inf.ed.ac.uk/research/programmes/comp-think/). At each seminar, one or more experts have discussed the influence of computational thinking on their discipline. We have enjoyed a stellar cast of speakers from a wide range of disciplines. Speakers have included the Principal of the University and three Vice Principals. The disciplines have ranged from physics, biology, and medicine to philosophy, architecture, and education. Often the influences described have been quite subtle. A common story is that the most direct approach does not work for some interesting reason, but that a less direct approach is having a more profound effect.

2. New Kinds of Questions New Kinds of Answers

Let's start with perhaps the most obvious influence of computers in research, especially in the sciences: e-Science. Many scientific questions can only be addressed by collecting and analyzing vast amounts of data. The resulting data collections are often so large they are prohibitively expensive to send to the processor; the processor must come to them. They are often also distributed across multiple sites, meaning that Grid-like organization of data sources and high-performance processors are required to combine and analyze the data, extract answers and present them in a digestible form.

Many sciences now present research questions in this form. They include particle physics, astronomy, genetics and protoeomics, and the earth sciences. In the UK, we have had, for several years, a multi-million pound, national research program in e-Science that cuts across many disciplines and funding agencies. Edinburgh was chosen as the host for the National e-Science Centre, so we are especially aware of the challenges and opportunities of e-Science. The role of computer science in this story is no longer seen as the software-engineering hand maiden, but as part of the scientific agenda: producing new tools for data-mining, visualization, distributed programming, etc that enable new kinds of research opportunities.

Several of our Computational Thinking seminars took the e-Science theme. For instance, Geoffrey Boulton explained how computer modeling had enabled geologists to take a more holistic approach to understanding the Earth. Traditionally, geological narratives tended to be direct, uncoupled and linear --- underestimating the complexity of the interactions between different geological processes. High-performance computer modeling has, for the first time, enabled geologists to do justice to this complexity and thus obtain a deeper geological understanding. Such in-depth understanding is vital if we are accurately to understand, predict and influence the mechanisms involved in climate change.

Andy Lawrence and Bob Mann extended this discussion beyond the Earth to the stars. The Virtual Observatory is an attempt to federate the data from the current wave of systematic sky surveys being undertaken across the electromagnetic spectrum, and to present a unified view to astronomers all over the world. This will enable astronomers to make sense of this huge and diverse amount of data, and assist them in formulating and evaluating new hypotheses. Lawrence and Mann especially emphasized the intimate collaboration between computing and astronomy that was now driving this research. It was no longer just astronomers using computers to solve isolated problems, but a two-way collaboration creating a new science of astro-informatics, which was a model for new disciplines of x-informatics for many new values of x.

But the ability of Computational Thinking to help ask new research questions is not limited to e-Science. Work on face recognition, by Vicki Bruce and her collaborators, was made possible only by using image morphing techniques, as illustrated by the well-known sequence of images changing Tony Blair into Margaret Thatcher in 5 stages. Bruce's early experiments with photos, scissors and paste were too crude to provide the fine gradations between images needed to separate rival psychological hypotheses. Bruce et al's work also showed that one cannot simply adapt the feature-based approaches of early computer vision work and hope that this will provide a ready-made psychologically-valid account of human vision. Instead, faces seem to be encoded in memory by abstracting them into a small collection of archetypes. Face recognition then consists of matching the current image to the most similar archetype.

3. New Hypotheses; New Theories

Bruce's team's work also illustrates the second major theme in our Computational Thinking seminars: the infiltration of computational metaphors into hypotheses and theories. Her psychological theory of face recognition is formulated as a computational process, employing techniques for abstraction, representing and formulating archetypes, ‘nearest neighbor’ matching, etc.

Systems biology is probably one of the best known examples of such computational infiltration, particularly the use of computational procedures to represent the interaction of biological processes. Jane Hillston described her use of probabilistic process algebras to model the interaction of proteins within and between cells. Peter Ghazal discussed how computational models could be used to both understand cells and proteins, but also to understand how and why they went wrong in disease and what interventions might cure them.

Perhaps the longest standing computational metaphor is that of the brain as a computer and the mind as the program running on it. Philosophy has now moved on from using this metaphor as an explanation of the mind-body problem, to considering some more subtle issues. Andy Clark addressed the apparent paradox between the fast feedback required for some simple manipulation tasks and the fact that our perceptual system is not capable of giving such feedback fast enough. He proposed a computational explanation: that we have an ‘emulator circuit’ that predicts what the feedback ought to be. This emulator also provides an internal representation of our bodily functions, which can also be used, for instance, for planning and hypothetical reasoning.

4. New Thinking; New Angles

According to Burkhard Schäfer, Computational Thinking has a long tradition in influencing the law, especially in the dream of providing a set of logical rules that can automate the process of reaching a verdict. Arguably, such a computational dream underpins the Napoleonic Code and its desire to minimize human discretion and maximize predictability of outcome. Unfortunately, this dream ultimately flounders on the inherent vagueness of words and the infinite and unpredictable variation of the real world. Similarly, \`expert system' like replacements of the judiciary have a poor record both of success and of uptake. However, legal reasoning systems have been making inroads where they merely try to assist those making legal decisions. For instance, researchers at the Joseph Bell Centre have built a system that constructs a space of hypotheses to explain the evidence in a crime scene. This has been used to remind detectives of hypotheses they might otherwise have missed. Such \`mind-expanding' aids avoid the pitfalls inherent in the earlier \`mind-narrowing' ones.

An almost identical point was made by David Glasspool in the context of clinical medicine. Automated decision making is mathematically well understood and straightforward to implement, but computational aids based on these techniques have often been ignored by clinicians. The precise probability and utility measures required by such aids are hard to come by, especially in the time-frames dictated by urgent medical situations. Much more useful has been \`mind-expanding' aids that, for instance, map out the space of possible treatments and their likely effects, so that doctor and patient can be better informed before they come to a considered decision. Glasspool demonstrated just such an aid showing the likely effects of different treatments for breast cancer, and how these effects will combine and interact over the course of a proposed treatment.

5. Conclusion

These are just a few of the many talks in our Computational Thinking seminars, but they are enough, I hope, to illustrate the breadth of impact of computational thinking on every kind of thought. Despite this breadth, the same key themes keep emerging from each discipline: the ability that computation provides to investigate new kinds of question; the infiltration of computational concepts into other disciplines' theories; and that computation's influence is seldom what you might initially predict, but is often both more subtle and more profound.