Clear Thinking about Artificial Intelligence *

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In recent years artificial intelligence (AI) has become more mathematical. The 'empirical programming' methodology is no longer the norm. AI researchers have been extracting 'neat' techniques from their 'scruffy' programs and formalising them. Mathematics is often found to provide an appropriate language for this formalisation. New uses are being found for mathematics in every area of AI. Where existing mathematics is not up to the task, new kinds of mathematics are being invented.

Mathematics has played some role in AI since its inception. This role is stronger in some areas than others. For instance, mathematical logic has always played a major role in knowledge representation; geometry in visual perception and grammars in natural language understanding. But gradually, since the 1970s, this role has increased in several ways.

- New kinds of mathematics have been used in these already mathematical areas of AI.
- Areas of AI that were not previously very mathematically oriented have started to experiment more with mathematical techniques.
- New kinds of mathematics are being developed in AI.
- Experimental programming is no longer the dominant methodology of AI.

To give a flavour of these developments here are some examples.

- The knowledge representation area is now completely dominated by logic-oriented research, as evidenced by a glance at the proceedings of the last few KR conference proceedings.
- In the last decade the vision area has started to use fractual and stochastic geometry, the calculus of variations and non-parametric estimation, among many other new techniques.
- Similarly, the natural language area has started to use statistics on large corpora of examples.

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- Statistical mechanics and chaos theory are being used to understand the global behaviour of neural nets.
- The new learning sub-area of inductive logic programming combines techniques from logic and from information theory.
- Operations research and plan formation are becoming more closely integrated.
- Approaches based on probability theory have largely replaced more *ad hoc* approaches to the representation of uncertain reasoning.
- Non-well-founded sets are being used to represent knowledge and belief.
- A variety of non-monotonic logics have been developed by AI researchers to represent default reasoning.
- New kinds of logic are playing a key role in the parsing of natural languages.

Why is this happening? I believe it is an inevitable result of the increasing maturity of AI. Artificial intelligence has proved much more difficult to achieve than was initially assumed. AI researchers have abandoned the 'quick kill' and have settled down for the long haul. They have learned from experience that, while experimental programming is a useful generator of ideas, it is not a good basis for developing robust and reliable computer systems. Nor is it going to be possible to build an all-singing, all-dancing, intelligent robot in the foreseeable future. They have settled for a careful and detailed exploration of the different programming techniques that go to make up intelligent behaviour. They are using mathematical tools because they assist clear and careful thinking.

These developments have taken place, for the most part, within academic research and have not had time to filter down to industrial applications. This technology transfer is bound to happen over the next decade. Industry wants more powerful programming techniques and it wants robust and reliable programs. The rule-based programming techniques, which date from the mid-70s, will be supplemented by a wide variety of more powerful and versatile AI techniques, many of which will have a firm mathematical base.

Will industry be ready to accept this transfer of mathematically oriented technology? Success will depend on these factors:

1. The extent to which AI researchers are able to hide the mathematical exotica within an attractive and intelligible package.
2. The mathematical sophistication of the system developers who might benefit from this new technology.
3. Demonstrations that mathematically based approaches can cope with the complexities of real applications.

Factor 1 depends on a recognition of the problem by AI researchers and funding agencies and some imaginative use of human-computer interfaces, *etc.* Factor 2 depends on the modernisation of AI teaching to include some of the new branches of mathematics that are being used in AI. We must educate AI experts who are comfortable with these mathematical developments. Factor 3 depends on a few AI researchers having the courage to test their mathematical techniques on hard problems. There are signs that this is beginning to happen, although there will always be a lag between theory and practice.