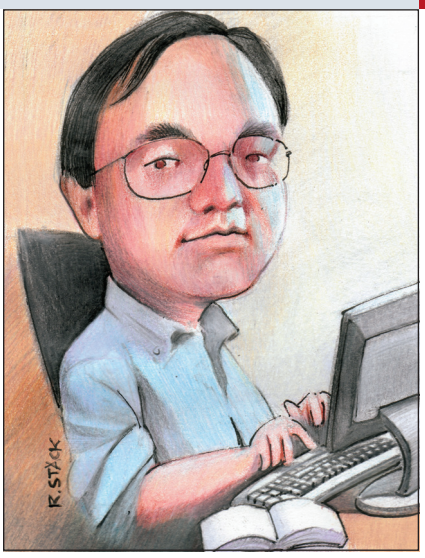

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From Computational Thinking to AI Thinking

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It's safe to say that Economics and AI have had a complex relationship. After all, one of the founding fathers of AI, Herbert A. Simon, is a Nobel prize-winning economist. Concepts from various subareas of economics, notably microeconomics and game theory, have been a major influence to AI research, which needs help with modeling individual rationality and strategic interactions.

Conversely, frameworks from AI—such as those based on bounded rationality and computational problem solving—have made valuable contributions to economic inquiries. Yet, it's still fascinating to note the prominent role AI is playing in the recent writings of another Nobel prize-winning economist, Paul Krugman.

Moving into the Mainstream

As a *New York Times* columnist, Krugman has written extensively on the engine of economic growth, an important macroeconomic topic, and its AI connection. In his op-ed piece "Is Growth Over?" (see www.nytimes.com/2012/12/28/opinion/krugman-is-growth-over.html), he discussed that "the field of artificial intelligence has for decades been a frustrating underachiever, as it proved incredibly hard for computers to do things every human being finds easy," and that "the barriers seem to have fallen—not because we've learned to replicate human understanding, but because computers can now yield seemingly intelligent results by searching for patterns in huge databases." As intelligent machines may soon be able to perform many tasks needing human attention and human labor, "this will mean rapid productivity growth and, therefore, high overall economic growth." In his blog "Gordon Versus The Androids," Krugman talked again about his optimistic prediction about the success of AI and its positive impact on productivity (see http://krugman.blogs.nytimes.com/2013/12/07/gordon-versus-the-androids/?_r=0).

Optimistic or pessimistic viewpoints aside, the fact that a noted economist has been writing about AI in one of the most important and widely read news media outlets in an ongoing dialogue about today's and tomorrow's economies and economic policy-making, and the fact that many of these AI-related pieces have attracted a large number of comments from the readers, are clear indications that AI has entered the consciousness of the general public. Unlike the early days of AI, when the general public was fascinated by AI applications' novelty, interestedness, and sci-fi-like attraction, in today's IT-enabled technology society, people are accepting the fact that AI applications are anytime and anywhere, and that AI is already an indispensable part of working, personal, and social life. From a business perspective, AI has become an enabler for

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Published by the IEEE Computer Society

a wide array of industries and holds major promise for productivity gains, and emerging and new business models. AI is also playing an increasingly important role in governments, in terms of both policy-making and government operations. It suffices to say that just like computer science, AI has grown way beyond a branch of academic research. Its societal impact and potential have made it a technological pillar of modern society.

Expanding AI's Reach

In March 2006, Jeannette Wing published an influential piece in the *Communications of the ACM* on "Computational Thinking," proposing the idea that computational thinking "represents a universally applicable attitude and skillset everyone, not just computer scientists, would be eager to learn and use" (see doi:10.1145/1118178.1118215). Given the ubiquity of AI in modern life, and the way AI has "incubated" many subareas that now have grown into their own relatively independent fields, with many novel applications (and in some cases industries) rooted in AI ideas and techniques, I would argue that it's high time for the AI community to conceptualize "AI thinking" and come up with an actionable plan to steadily move towards it.

Obviously, AI thinking and computational thinking are interwoven and overlapping as computing-enabled machine intelligence is a primary means to realize intelligence. Many ingredients of computational thinking—such as the power of abstraction, use of heuristics as a problem-solving technique, and importance of statistical learning and data science—directly apply to AI thinking. Yet, AI thinking needs to go beyond what computational thinking offers.

Here, we attempt to provide a bit of substance to AI thinking, fashioned after computational thinking. AI thinking is concerned with frameworks, skillsets, and general tools that are distilled from AI research and practice and are of general interest to everyone, not just AI researchers. Compared against computational thinking, AI thinking goes beyond the logic- and algorithm-based perspectives and should emphasize items such as how to

- leverage knowledge bases and case bases in problem solving,
- capture and reason about commonsense,
- enable processing of semantics and contexts, and
- deal with unstructured data, among others.

It should also cover the basic ideas behind deep learning and cognitive computing. In addition to overall frameworks, AI thinking should also include what AI has to offer concerning generic problem solving: a small set of mature, widely applied knowledge representation ideas, and the corresponding readily pluggable reasoning engines.

As in the case of computational thinking, perhaps the most direct implication of AI thinking is in the formal educational setting. Recognizing what AI can offer to various disciplines without teaching the students specific AI problem-solving techniques or programming skills, AI thinking could become an integral part of supplying students with an educational foundation in computing across the campus. Curriculum for such a course or a major module of a Computational Thinking course would need to be developed by the AI community. Different from a standard AI introductory course, this course should focus on frameworks and big ideas, more concretely illustrating links with

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disciplines that have benefitted from AI methodology, especially those that aren't computational in nature. Integrating AI thinking into such a foundation of learning serves multiple purposes. For instance, it serves as a recruiting tool to attract young talents into the AI field. It also better equips students in other disciplines with new insights into modeling, problem solving, and data analytics, among others.

AI thinking should not stop at formal educational settings. The AI community must do much more to better inform the general public, businesses, and policymakers about what AI has done and can do in the future. AI thinking can be the messaging framework. Which industries have been developed mostly out of the ideas from the AI community? How has AI helped with everyday mobile phone applications? What are the AI principles driving smart cars and drones? How can AI help enable smart health? How is Wall Street benefitting from AI? How are AI techniques helping governments respond to emergencies? What are the ethical issues connected with adopting AI systems? Such outreach and general education efforts must be consciously coordinated by the AI community using a minimum set of carefully chosen technical vocabulary, easy-to-understand and precise claims, and vivid case stories.

To articulate what AI thinking is about more comprehensively and precisely is beyond what this article can accomplish. In effect, AI thinking will likely remain a dynamic working notion needing updates and revisions. Adapting from the last sentence of Wing's 2006 article on computational thinking, let's "spread the job, awe, and power" of AI, aiming to make AI thinking commonplace. ■