Kyle J. Behymer, Infoscitex, USA
John M. Flach, Wright State University, USA

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From Autonomous Systems to Sociotechnical Systems: Designing Effective Collaborations

Abstract Effectiveness in sociotechnical systems often depends on coordination among multiple agents (including both humans and autonomous technologies). This means that autonomous technologies must be designed to function as collaborative systems, or team players. In many complex work domains, success is beyond the capabilities of humans unaided by technologies. However, at the same time, human capabilities are often critical to ultimate success, as all automated control systems will eventually face problems their designers did not anticipate. Unfortunately, there is often an either/or attitude with respect to humans and technology that tends to focus on optimizing the separate human and autonomous components, with the design of interfaces and team processes as an afterthought. The current paper discusses the limitations of this approach and proposes an alternative where the goal of design is a seamless integration of human and technological capabilities into a well-functioning sociotechnical system. Drawing lessons from both the academic (SRK Framework) and commercial (IBM's Watson, video games) worlds, suggestions for enriching the coupling between the human and automated systems by considering both technical and social aspects are discussed.

Keywords
Human-autonomy interaction
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Emails
Kyle J. Behymer
(corresponding author)
kbehymer@infoscitex.com

John M. Flach
john.flach@wright.edu

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Introduction

The goal of this paper is to argue that effective collaboration is critical to the success of human-machine teams, and to provide a framework (illustrated in Figure 1) for addressing the coupling between humans and machines such as autonomous agents. This is particularly important in the context of sociotechnical systems where multiple agents must collaborate to solve complex or wicked problems.[1] We will begin with a brief example to illustrate some of the dynamics of effective collaboration.

In 2005, Playchess.com hosted a chess tournament in which teams of human players could use computer assistance during matches.[2] The chess super computer Hydra was also entered into the competition, and after recently defeating Grand Master Michael Adams 5 ½–½ in a six game match, was considered to be the prohibitive favorite. Surprisingly, Hydra was eliminated before the semi-finals, with three of the four semi-finalists consisting of Grand Master-led teams equipped with supercomputers. Even more surprising was the fourth semi-finalist and eventual winner, team ZachS, composed of two relatively amateur chess players named Steven Crampton and Zackary Stephen using ordinary computers.[3]

The Elo Rating system[4] – a method of rating chess player skill level based on head to head results – puts team ZachS's victory into perspective. Table 1 lists Elo ratings ranging from novice to world champion. Current world champion Magnus Carlsen obtained the highest Elo rating (2882) in history for a human player (Garry Kasparov's best was 2851, Bobby Fischer's was 2785).[5] At the time of the tournament, Hydra's estimated Elo rating was 3000, and the runner up team was led by two 2600+ Grand Masters. Crampton and Stephen's Elo ratings were 1685 and 1398 respectively.[6]

Team ZachS was vastly outclassed in chess skill and computer hardware, yet overcame Hydra and the Grand Masters armed with super computers by quickly and efficiently manipulating their machines to deeply explore relevant positions and shrink the search space for their chess computers.[7] The higher skill level of Hydra and the Grand Masters equipped with super computers was not enough to overcome the seamless collaboration between the less skilled amateurs and their weaker computers. As Garry Kasparov stated, "Weak human + machine + better process was superior to a strong computer alone and, more remarkably, superior to a strong human + machine + inferior process."[8]

Table 1. Chess Elo Ratings.

Elo	Skill Level
<1200	Novice
2000	Expert
2400	Master
2600	Grand Master
2700	World Champion

Synergy

In fact, the human-machine combination has the potential to outperform human-alone and computer-alone in many domains. For example, human forecasters at the National Weather Service can improve the accuracy of computer precipitation forecasts by 25% and computer temperature forecasts by 10% over computer-only forecasts,[9] and human-computer teams have the potential to outperform both doctors and computer algorithms at correctly interpreting mammograms.[10]

However, as the chess example illustrates, group performance is more than the sum of the abilities of the individuals that compose the group. For example, the collective intelligence of a group of people is more highly correlated with the group's social sensitivity, equality in turn taking, and the number of women in the group than the average intelligence of group members or the IQ of the group's

1 For discussion of 'wicked problems' see Richard Buchanan, "Wicked Problems in Design Thinking," *Design Issues* 8, no. 2 (1992): 14–19.

2 Various names have been proposed for this type of chess, including advanced chess, cyborg chess, centaur chess, and freestyle chess.

3 Clive Thompson, *Smarter Than You Think: How Technology is Changing Our Minds for the Better*, reprint ed. (New York: Penguin Books, 2014), 4–5.

4 The Elo Rating system, developed for chess by Arpad Elo in 1978, has also been used to measure skill level in many sports including baseball, basketball, football, soccer, and tennis.

5 Ratings from http://www.chessgames.com/chessstats.html.

6 "Dark Horse ZachS Wins Freestyle Chess Tournament," *Chess News*, last modified June 19, 2005, http://en.chessbase.com/post/dark-horse-zacks-wins-freestyle-che-tournament.

7 Garry Kasparov, "The Chess Master and the Computer," *The New York Review of Books*, February 11, 2010, accessed September 17, 2016, http://www.nybooks.com/articles/2010/02/11/the-chess-master-and-the-computer/.

8 Ibid.

9 Nate Silver, *The Signal and the Noise: Why So Many Predictions Fail—But Some Don't* (New York: Penguin Books, 2012), 125.

10 Mark Gaynor, George Wyner, and Amar Gupta, "Dr. Watson? Balancing Automation and Human Expertise in Healthcare Delivery," in *Leveraging Applications of Formal Methods, Verification and Validation. Specialized Techniques and Applications*, ed. Tiziana Margaria and Bernhard Steffen (Berlin: Springer-Verlag Berlin Heidelberg, 2014), 561–69.