Comparison of the breadth, depth, and kinds of thinking required in three-way vs. two-way chess, with possible implications for human-computer competition

(DRAFT3)

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Summary. This note briefly discusses the kinds of thinking (cognitive processing) required at different levels of play in two- vs. three-way chess[2]. It starts with a comparison at the most primitive and obvious levels (e.g., mentally grasping a configuration of pieces, remembering sequences of play) and proceeds through comparisons at successively more sophisticated and higher levels of cognition (e.g., assessment of patterns, anticipation of consequences, construction and appreciation of strategy, etc.). It is not surprising that three-way chess makes modestly heavier cognitive demands at basic levels of play, because there are more pieces, players, and a larger board. It appears, however, that the real differences emerge at higher levels of play. Both psychological and information theoretic considerations seem to indicate that *advanced* play in three-way chess is by nature (a) significantly "harder" (requiring more of each basic ability); (b) more "strategic" because it profits less from simple evaluation of foreseeable outcomes and instead requires thinking that is more abstract; (c) more "multidimensional" because it requires added skills of perception and assessment of one's opponents and their interactions, and can profit from skillful manipulation of their perceptions and motives; and (d) by virtue of the need for exceptionally flexible integration and use of all these and other skills, it places greater demands on overall fluid general intelligence or "g". One key reason for these differences is that three-way chess has a much more rapid growth of possible consequences of a move as one tries to look several moves ahead (the so called "combinatorial explosion"). This reduces the maximum feasible depth of exhaustive forward search, which enhances the need for other, more abstract and "strategic" approaches. Another reason is that a game incorporating three players requires greater strategic appreciation of one's opponents as human agents. Together, these two differences suggest that grandmaster level three-way chess currently is (and, in the foreseeable future will remain) beyond the reach of artificial intelligence.

Levels of play

Grasping a single configuration. At the most elementary level is the relative difficulty of comprehending a single chess-board configuration. The first and most obvious fact is that more things are involved: the three-way board is larger (147 vs. 64 cells), and there are more chess pieces (initially, 75 vs. 32, with each player having 25 rather than 16);

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[2] at least for the "H-variant" being discussed here (for rules and details on the "Harshman et al." variant, see, e.g., www.threewaychess.org).

even as pieces are eliminated, there are usually more remaining in play at any given stage of the game. Second, each of these things has more potential connections to the others, because the hexagonal playing grid provides 12 directions rather than 8 leading into or out of any cell, and this creates more simultaneous geometric relationships to encode. Third, to understand the current configuration one must grasp its capture relationships: not only the relationships between each of one's own pieces and two different sets of opposing pieces, but also those between the two opponents' pieces.

When the pieces are in their initial positions, these differences do not matter, since everything is familiar and already cognitively "chunked". Naturally, as the game evolves, less familiar configurations arise and new "chunks" must be constructed, at which point the increase in properties and components to be integrated makes this task more cognitively demanding. This also holds at the higher level of "chunking" that experienced players will use; the three-way nature of play requires more chunks and more relations among them. Put pictorially, there are three distinct armies and they generate three interacting "fields of force".

At some points in any three-way game, there will be critical board positions where the overall growth in cognitive demand is approximately the product of the individual increases in number/complexity of relationships. At such points, even the "simple" task of grasping a single board configuration will involve heavy demands on a player's breadth of awareness and on the capacity of both abstract and geometric immediate memory, demands significantly heavier than would be likely to arise in two-way chess. A literal interpretation of the increase in the size of these various factors, if multiplied together, produces a large value which no doubt overestimates the increase in cognitive demand involved at this elementary level of processing, particularly for skilled players. But it seems reasonable to conclude that there could often be a noticeably greater cognitive demand involved in fully grasping a single board configuration, perhaps by a factor of 2 to 3 and sometimes even more. It even seems possible that infrequently, board configurations could occur which would require so much low-level immediate processing ability that to fully grasp them would be beyond the functional capacity of all but the most gifted minds.

Sequential events. Appreciating and storing the progression of positions is also in some respects more demanding. Each round of play changes the position of three rather than two pieces, which means that, for any particular player, there are *two* opponents' moves that will occur before play is returned to him/her, and these two moves are not independent, because the first opponent to move changes the board that the second opponent then responds to. Prediction of that response requires interpretations at multiple levels that need to be stored along with the literal facts involved in each of the two opponent's moves. Naturally, this all increases the load on short term memory, particularly when several levels of information/interpretation need to be stored for each event during each of several rounds of play.

Parallel assessment of the move patterns of both opponents and their interactions.. For skilled players, the increase in processing demands described above are probably not the main challenge. A greater, though not necessarily the greatest, cognitive processing challenge probably arises from the need to consider, at multiple levels, the actions of two

opponents simultaneously. This potentially puts very heavy demands on what current psychological theory calls "working memory"[3].

Many players, particularly at lower skill levels, may simply give up on any attempt at fully parallel consideration of actions by both opponents, and instead may choose to concentrate mainly on one opponent. This choice is problematic, of course, since it not only makes one less aware of threats from the other opponent, but also makes one less likely to notice implications of both opponents' play in relation to each other, implications that might have significant future importance.

There are periods in a three-way game during which the number of different levels at which the history of recent moves can be considered (including the psychological levels to be discussed below), and the possible range of alternative pairwise and three-way interpretations that could be made at these different levels, along with their potential strategic implications, are simply too much for anyone to fully deal with. Inexperienced three-way chess players are unlikely to notice this potential for multilevel richness in content, however, because the mere technicalities of play will, in themselves, absorb all of their functional capacity. Much of this richness springs from psychological dimensions of the game, some of which will be discussed below.

Forward anticipation of consequences. "Depth" of thinking in chess involves more than grasping, processing, recalling and interpreting the events of the last few rounds of play. Skilled chess play necessarily involves *anticipating* future consequences, looking *several moves ahead.* The more skilled and/or talented the player, the deeper is his forward search of the branching tree of future possibilities.

In three-way play, the number of possible sequences of events that must be traced forward at each further step into the future grows much more rapidly than it does in two-way chess. This is a very important and powerful difference between the two-way and three-way games[4]. Even when future chains of events are considered at the more abstract level likely to be used by an expert player (e.g., in abstract action-units such as "ploys", "assaults", "replies" etc.), the task of anticipating consequences of strategic choices is made more cognitively demanding because the reactions of two opponents need to be considered, *along with their interactions* (i.e., the cross-reactions of each opponent to the other's response to a strategic action).

Because the growth of alternative possibilities explodes exponentially as one tries to extrapolate successive steps into the future, the "event horizon" beyond which even expert players cannot clearly see is moved closer to the present. Consequently, a skilled player's ability to choose winning moves by sheer wealth of knowledge and intensity of intellectual effort is significantly reduced. This then leads us to the interesting possibility

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[2]Psychologists don't all define "working memory" in exactly the same way; we here mean the mental ability to keep several items simultaneously current or active in a background awareness so that they are independently and immediately available to interact with one another, trigger action, or be manipulated as the ongoing task requires. Greater "working memory" allows more items to be held available in this fashion.

[4] When only two players are contending, as happens in Stage 2 of a Second-Mate game, the rate of growth of possible outcomes per round of play is reduced, but it is still faster than in regular chess, because of things like the hexagonal playing grid which provides more directions of interaction, and the greater number of pieces typically remaining in play.

that, once the technicalities of play have been mastered and expert players have begun to emerge, alternative dimensions of strategy will take on increased importance.

The increased importance of "psychology". We have discussed above how three-way chess is more cognitively challenging at a purely intellectual level than two-way chess, but it is also in some sense "richer" at a psychological level in that new dimensions of mental perception and skill are involved. With three players, understanding the mindset and personality of one's opponents becomes relatively more significant, and the psychological interaction amongst the players now becomes strategically important. Rather than simply assessing the change in strategic position after one's move, the other two players must try to guess what was the motivation behind the move (was it directed at one or the other or both?). This introduces the possibility of new dimensions of play involving manipulation of the cooperative or competitive interactions of one's opponents with each other and with oneself. For example, one might infer that an opponent has adopted a certain strategy relative to the other opponent, and take this into account in planning moves. These agent-oriented strategies make it even more important than before to have insight into the "human" nature of the players (both how they relate to oneself and how they relate to each other), as well as the nature of the progress of positions on the board.

Implications for computer-human competition

For a given move in chess, computers exhaustively search the forward branching tree of consequences. However, this quickly becomes infeasible in three-way chess as the number of possible outcomes grows doubly-exponentially, and so the computer advantage is reduced. In addition, a good three-way player must use intuition or psychological inference to imagine how the two opponents view him/her and each another. This sort of inference and insight is beyond the current reach of computer programs and artificial intelligence. Thus, it would seem that humans might have the edge in a human-computer three-way chess match.

Of course, the sheer volume of possibilities limits *both* humans and computers in terms of how far ahead it is feasible to project alternative moves and strategies. Humans might have an advantage in this situation, however, because they can make better use of abstract strategies that would be difficult to program for a computer, and can change these strategies more fluidly, as circumstances require.

More important is the psychological aspect of the match, which is even more difficult to program. This would be less salient in a one-human-two-computer game, but would certainly be present in any match involving two humans and a computer. Both humans can use psychological assessments in planning strategy to get the better of the other human, and they can modify their assessments and strategies depending on the circumstances, whereas the computer cannot. The human advantage involves abilities that are quintessentially "human": understanding the ideas, intentions, emotions, and personality traits of one's opponent. Not only do these truly psychological skills operate outside the domain of exhaustive search of board positions, functioning at this level seems beyond any near-term capabilities of artificial intelligence. It requires some of the same sorts of abilities needed to truly understand natural language.

To the extent that this analysis is correct, then, humans may be able to reclaim supremacy at chess. If three-way chess is the most challenging form of chess, the claim that computers can outplay humans should not be accepted until they can defeat humans at this game. But if, as our analysis also indicates, being a good three-way chess player requires particularly flexible and high fluid intelligence or "g", along with good insight into (and even the ability to manipulate) the mental states of one's opponents, then computers would not likely gain chess supremacy until they have themselves become much closer to "being human".