Collaboration among specialists: Comparison between humans and cognitive machines.

The need for it.

The world is a complex place, one might even dare to suggest a very complex place! One way people have coped with this complexity is to break it down and compartmentalise knowledge into smaller areas or specialties. It might take a lifetime for someone to become an expert in a small area of knowledge and be able to solve problems that fall solely in their area of expertise without collaborating. However, most problems in the world, especially the important ones, don't fall within a small specialisation – they are huge, complex, intertwined and have far-reaching implications to life on Earth, now and into the future. Thus specialists need to collaborate to define and solve these problems [1] [2].

One such problem is climate change (global warming). It's a global problem with far-reaching effects on sea level and weather patterns, the natural environment, agricultural productivity, biodiversity, global food supplies, poverty and the spread of disease. Even defining the problem, and identifying the contributing factors, requires a raft of experts from wide-ranging scientific disciplines to collaborate (for example see [3]). When it comes to solving the problem and implementing the solution, specialists in economics, energy production, politics and the media are needed to join the collaboration, because a solution may involve changes to world economies, energy production, standards of living and world population.

The current global pandemic, COVID-19, is another of these huge, complex problems facing the world. How does a country's leaders navigate their people through a pandemic in such a way to preserve the health and well-being of its people, maximize the number of people in employment, provide welfare support without leading the country to future financial ruin, develop a vaccine, provide support to other countries needing aid and avoid a second-wave? To deal with such questions, the German Federal government looked to a working group from the Leopoldina, Germany's independent National Academy of Sciences, for advice [4]. The working group consisted of 26 specialists including philosophers, historians of science, theologians, jurists, ethicists, as well as natural scientists, virologists and medical specialists. The Australian government has also put together a committee of experts to form the National COVID-19 Coordination Commission [5], to advise of the best way forward considering the wide range of political portfolios effected by the pandemic. The Irish government has done likewise [6]. The World Health Organisation (WHO) and China formed a joint mission of specialists from different disciplines to rapidly inform national (China) and international planning on next steps in the response to COVID-19 in February, 2020 [7].

The benefits of it

Synergy is the driving principle for collaboration between experts from different fields – the possibility that the interaction or cooperation of two or more specialists will produce a combined effect greater than the sum of their separate effects. How could this be if the specialists are from different disciplines?

Specialists from different disciplines think differently to one another; problem-solve differently to one another, so when they all focus on the same problem together, multiple perspectives to the problem will emerge. Sometimes a solution to a problem can fall out naturally once the problem is viewed from a particular perspective. Also, if one specialist in the team drafts a solution to the problem, other members of the team with different backgrounds may be able to identify missing steps in the solution or complications the first specialist overlooked. Through discussion, cross-fertilization of ideas between the specialists can occur and the team develops new ideas, perspectives, theories and solutions that would never had been reach without collaboration.

Specialists from different disciplines tend to work towards different goals. For example, epidemiologists may advocate rolling cycles of 50 days lockdown by 30 day relaxation over the next 18 months to control the COVID-19 pandemic [8], but economists would prefer a gradual return to work to restart the country's economy. By collaborating on a problem that involves multiple disciplines, team members can identify when a solution proposed by one expert has detrimental outcomes for their own specialist area, and a more "globally-optimal" solution can be sought.

Once a solution has been devised, it must be implemented. The solution to a big, complex problem will require the cooperation of the wider community. The benefit of the solution coming from a multidiscipline team of experts is that you are more likely to get the "buy-in" of the wider community. Different members of the wider community will sympathise and trust the advice of some specialists, whether that be politicians, economists, scientists or doctors, over others. If their favourite expert is part of the committee, they will feel their perspective has been taken into account when solving the problem and will more likely accept and play their part in implementing the solution.

The difficulties of it

Several difficulties arise when specialists from disparate fields collaborate to solve a problem; difficulties associated with a team of specialists collaborating and difficulties because the problem is dynamic, changing and developing while the committee of specialists is trying to solve it!

Difficulties associated with specialists collaborating

When a group of specialists collaborate to solve a problem several difficulties can arise; communication difficulties, difficulties compromising on problem solving constraints, mistrust among specialists and mismatches in understanding between specialists even after collaboration, so a unanimous decision is not reached.

Communication difficulties can range from the obvious to the more subtle. Starting with the obvious, specialists brought together to collaborate may come from different countries with different cultures, speaking different languages. Even if they can all speak a common language, their accent may complicate verbal communications. In addition, specialists from different disciplines use different technical language; certain words or phrases will have a very specific meaning in one discipline, while it will be either completely unknown in other disciplines, or take on a very loose meaning. For example, if you use the term speed and velocity interchangeably in front of a physicist, they will probably let your mistake slide, but inwardly they are twitching!

More subtle communication difficulties can arise when the specialists across all fields share some basic common knowledge. Studies have found that a group of experts will more likely focus on that common knowledge in discussions rather than on something only one expert knows [9]. This counter-acts the purpose of bringing specialists from different fields together to collaborate. Additionally, a specialist in the team may not speak up with valuable information or contradict another specialists if they don't feel "psychologically safe", that is they aren't confident that the team won't embarrass, reject or punish someone for speaking up. Unfortunately people, whether they be specialists or not, are social beings and are affected by group dynamics. And since the other experts can't see inside their brains, they can't know if they are withholding relevant information, for whatever reason, or indeed even lying.

Specialists from different fields may have difficulty compromising on the constraints imposed when trying to solve a problem because they tend to have different goals or values that they normally optimise. If an amicable and optimal compromise can be reached, this can be a benefit of the specialists collaborating. However coming to a compromise is not easy for people, particularly specialists who are used to others taking their word for something because they are experts. Specialists are used to questioning others, because they are the experts in a field, and can want other experts to prove themselves before they will consider compromising. Without a complete understanding of the breadth of the problem they are trying to solve, a collaboration of specialists may need a third party, a generalist who sees the "big picture" and is an expert negotiator, to manage personalities in the group, and merge all their solutions to test how they work together and optimise overall. Of course, such a generalist is rare and highly sort after! If you can find such a generalist to manage the collaboration, they might not always improve things as they may miss important subtleties.

When specialists collaborate with others outside their field, they are learning new things. As they learn, they incorporate the new concepts/information into the current understanding structure they have developed inside their brain. This might involve slightly modifying their current understanding structure, but not greatly – they will hold to what they already know more strongly as they are experts in this area. So when two experts collaborate about a problem, they don't form a common understanding structure, they produce two modified understanding structures in their own brains – still different from one another by lacking detail in the other's specialty. This may still lead to misunderstandings, missed subtleties and multiple perspectives on the best solution to a problem. There is no guarantee that the team of specialists will unanimously agree on all facets of the solution their committee finally proposes.

The German committee formed to consider the Covid-19 problem is interesting, in that it has an ethicist – an expert on Immanuel Kant. Immanuel Kant's most influential positions in moral philosophy are found his work in *The Groundwork of the Metaphysics of Morals.* There he tries to "come up with a precise statement of the principle or principles on which all of our ordinary moral judgments are based. The judgments in question are supposed to be those that any normal, sane, adult human being would accept on due rational reflection". [10] In other words, he believed that rational people are moral, and hold to the same set of morals – a simplistic notion nowadays. Kant hinged his argument on our autonomy, but a committee, even the German committee made up of 26 people, is not autonomous in the way a single mind can be. Each member of the committee could be pulling in different directions based on differing moral standards. Will the ethicist in the German committee be as surprised as Kant would be?

Difficulties of solving a dynamic problem

Complex problems are often complex because they are dynamic. They can develop in ways that can't easily be predicted and modelled. They can evolve at rates much greater than solutions can be devised and implemented. And there can be exogenous events that occur that take the complexity of the problem to a whole new level.

Consider the COVID-19 pandemic for example. The mathematical model predicting how many Australians would die from the virus gave, thankfully, a gross overestimate. In March 2020, Australian policy makers were expecting up to 150,000 deaths based on a model initialised with a combination of Chinese and international data [11], but to date only 103 deaths have occurred. Why was the model so inaccurate? This was partly because the model assumed no lockdowns and no action taken by the community. And it wasn't initialised with Australian data. To get more accurate predictions on numbers of deaths, the mathematical model could have been re-run each day and included the number and location of new cases of COVID in Australia discovered in the last 24-hours. Just like the Bureau of Meteorology re-runs their mathematical models daily with the latest measurements included, to update their weather predictions [12].

But to be even more accurate, the mathematical model for the spread of COVID-19 in Australia may need an overall of its underlying structure. This would be a difficult thing to do, adding in new factors to the model that influence the result, especially where influences may flow in an as yet unknown direction. Did the model account for an unusually warm autumn day in Mid-March and how humans would then react? The virus spread more than expected in Sydney due to some Bondi beach and dinner parties that were held unexpectedly one warm autumn day [11]. Does the mathematical model include a prediction of how people would react if the updated findings of the mathematical model were increasingly optimistic, predicting fewer deaths than before? Would people keep taking social distancing rules seriously? And would people keep trusting the results of a model that was continually being adjusted? The mathematical model might need to factor in the effects of the predictions it itself makes in order to make more accurate predictions! But its structure isn't designed to adapt in this way.

Exogenous events have taken the complexity of managing during the pandemic in Iran and the USA to a whole new level. On May 7, 2020, an earthquake hit Tehran, Iran, driving people outside their buildings and into the streets without observing social distancing measures [14]. The problem of reducing the spread of the virus changes greatly if all of a sudden people can't self-isolate when they are experiencing symptoms or are highly vulnerable. A similar complication arose on April 12 and 13, in several southern states of USA when tornadoes tore through. People were *gathering*, albeit with face masks, in tornado shelters [15]. The death of George Floyd, an unarmed African-American at the hands of police in Minneapolis, Minnesota on May 25, 2020 [16] has led to unpredicted mass gatherings - public demonstrations and protests have been held across all 50 states of America, and in some international cities. How will the virus spread now, given these mass gatherings? The initial parameters of any model of human movement needs to be updated. Natural disasters and unpredictable social disasters like these have a huge impact on the COVID-19 problem. Any solution to managing during the pandemic needs to factor them in and make adjustments.

Implications for cognitive machines

Suppose we try to solve a big, complex problem by forming a committee of text-based, cognitive machines, each an expert in a particular field. How can the difficulties human specialists face when collaborating, inform and guide how cognitive machines should collaborate?

Happily some of the difficulties of communication will be removed. The text-based cognitive machines don't communicate verbally or with body language, so the possibility of miscommunicating with body language, or the intonation we use, or accent we speak with, is avoided. We will assume the collaborating cognitive machines haven't developed an ego (although each knows it's best at its own specialty and the other machines are best at their specialties).

Neither have they developed dominating personalities nor does the need to feel “psychologically safe”, so communication is not hampered by these human reasons.

But other communication difficulties remain. We’ll assume the individual cognitive machines in the committee are all designed to “read” English text. While this might seem somewhat artificial and biased, the problem of translating between different everyday languages is another large, complex problem itself. Google Translate has tried to tackle the problem [17], but the problem is by no means solved [18]. So assuming the cognitive machines all read English, the collaborating machines still face a communication difficulty because each specialist machine will understand technical language particular to their specialty domain, but not others. Just like a human expert would. Imagine each cognitive machine has an internal vocabulary particular to its specialty domain that it understands in depth. The collaborating cognitive machines are going to need to access each other’s vocabulary and knowledge structures to be able to communicate and build a greater understanding.

How should it work when we group specialist cognitive machines to collaborate? There’s at least a couple of approaches we could take.

Committee Chair Approach

When humans are brought together to collaborate, it’s for a reason, not just to exchange all the knowledge each possesses. And often one person acts as the chair of the committee, who leads and manages communication between committee members. So perhaps the specialist cognitive machines need to come under the management of a cognitive machine who has a general understanding structure of the problem in question. This cognitive machine could build up its understanding structure by accessing the understanding structures of the specialist cognitive machines. It also compromises between the goals and constraints of the individual specialist machines. The individual cognitive machines collaborate with the “committee chair” (CC) machine but not each other. The CC machine would end up with a grand understanding structure addressing the problem, but the understanding structures of the specialist cognitive machines remain unchanged. While this might avoid contradictions in the final understanding structure reached in the CC machine, it doesn’t seem to have captured the true essence of collaboration between experts. We didn’t let one of the committee come up with an idea that the others guide and develop to fruition. Somehow we’ve missed the point.

Round Table Approach

What if we do away with a committee chair?

Let’s return for a moment to what happens in a meeting between humans, possibly specialists, trying to solve a problem without a chairman. Pretend for a moment, everyone is very well mannered, respectful, good at listening and willing to contribute what they know to the discussion because they all want to solve the problem!

1. They come to the meeting, having already received and read the meeting agenda.
    a. Let’s assume the agenda is simple – it is about trying to solve a problem that intersects with each specialist’s field. The problem can’t be simplified further so all people at the meeting need to be involved with everyone else at the meeting to address the problem.
2. Specialists take turns explaining what they understand of the question/problem given their expertise.
    a. Each specialist doesn’t share all their knowledge, just the bits they think are relevant and the most important to the question.

   b. The order of specialists may greatly influence the course taken by the discussion, but if all the specialists in the meeting have something equally important to say, the order in which they share may be randomly chosen. For example, people are sitting around a table, and the person closest to the door starts, then they take turns moving clockwise around the table.
   c. As this is happening the understanding of the other experts is growing in a field outside their speciality. Questions may arise if the specialist can't graft these new concepts into their current understanding. The answers to those questions will allow them to form a connected understanding incorporating the new information.
3. Possibly then, someone tries to summarise the real problem, as they now understand it, highlighting the most important, or complicated part, to address, given a set of constraints.
4. Further specialists may contribute in turn to refine this summary until all experts are happy.
5. Once the problem is fully understood, one of the specialists (any one might respond first) would suggest either
   a. their optimal solution,
   b. or a partial solution,
   c. or a solution dependant on some hypothesis – something that they don't know but would make the solution work if it were true. (And even better, form an elegant solution!)
6. The other specialists process the proposed solution, adapting their understanding, figuring out the result of the proposed solution in their domain of expertise and then respond.
   a. Again, if they can't process the solution because there is a gap in their understanding, then they'd ask a question.
   b. If what the other specialist said is contrary to their understanding, they'd argue it out until one had showed the other was wrong (or someone got sick of arguing).
   c. If a partial solution was suggested, they might add to it to so that the partial solution becomes more complete.
   d. If a hypothesis was involved, they'd take the idea and see if it is consistent with their current specialist understanding, or whether their current understanding can be adapted in such a way to accommodate the new idea without compromising at least an interpretation of their existing understanding. If it's possible, they might suggest the implications of the new idea in their specialist area, then go on to suggest how it could be tested, or built upon with a further hypothesis.
7. Steps 5 and 6 repeat until
   a. a sufficient solution is arrived at by committee for the question,
   b. the solution cannot be developed further by the specialists until more external data is received,
   c. or time runs out.

How could a collaboration of specialist cognitive machines work similarly? What would be different?

1. The specialist cognitive machines would be brought together to address a problem that intersects each specialist's field.
2. Each specialist cognitive machine would share their current active structure which is relevant to the problem with the other machines.
   a. The amount of knowledge the specialist shares wouldn't have to be as limited as it was with human specialists. The other specialist machines don't have limited attention spans or the four-chunk information limit as humans do [19]. However, you wouldn't want to make this process longer than required. They'd share enough

   of their knowledge so that the other machines can connect in to their active structure in a useful way. (Remember the machines can "look into each other's heads".)
   b. This process wouldn't entirely be one way because the other machines are sharing their active structure back to "ask a question", to then receive enough information back to connect into the specialist machine taking centre stage.
   c. The order of "sharing" may well influence the development of the collaborative active structure. If 4 specialist cognitive machines are collaborating sequentially, there are 4! (4x3x2x1=24) ways they could share. Since these are machines that work fast, it may be worth re-running the conversation using every possible permutation and compare the collaborative active structures. This would show the degree to which ordering affects the outcome. Perhaps some orderings would give collaborative active structures with less inconsistencies than others. Some inconsistencies might be resolved in the collaborative active structure using one particular ordering that couldn't be resolved when another ordering was used, and vice-versa.

3. Once the collaborating specialist machines all finish adapting their active structures in terms of the problem definition, the collaborative active structure should be able to return a detailed understanding of the problem and the set of constraints for solving it.
4. Further refinement of the problem isn't necessary as the machines have been able to see inside the minds (active structures) of the others. There would have been no nasty surprises in step 3.

Steps 5 and 6 from the human model would be combined into one.

5. Each specialist cognitive machine would, in turn, share their current optimal solution with the other machines.
   a. This solution might be partial or based on a hypothesis.
   b. The other machines would process this by trying to connect more of their active structure in the "solution" area and would weigh its implications in their domain of expertise before responding.
   c. The response of the other machines might be to question, negate, build on the idea further or register that more external data is required to resolve that part of the collaborative active structure. At this point a different specialist machine has taken the stage and the whole step 5 repeats again.
   d. The order of this process may again be criterial to the final solution determined by the collaborating specialist machines. All possible permutations should be investigated to measure the effect of ordering on the final result.

Step 5 would repeat until the collaborating machines no longer update their active structures in terms of a solution – they have reached a sufficient solution given their collective current knowledge. The solution might not be complete if any of the specialist machines have registered they need more input to resolve hypothesises or inconsistencies. The solution might also be incomplete if the discussion process was cut short due to time limitations.

The round table approach for collaborating of machines might actually simplify further still. While humans segment the process of problem solving into two stages – first understand the problem properly, then figure out the optimal solution, machines probably wouldn't. So in step 2, machines could be both growing each other's understanding of the problem and growing a solution simultaneously. The problem solving process may actually stop at the end of step 3.

Keeping up, and overtaking, a rapidly evolving problem

How would a committee of specialist cognitive machines cope when solving a problem when it is rapidly evolving? Due to their speed of computation, probably much better than a committee of human specialists. New data could be incorporated into the active knowledge structures of the relevant specialist machines as it becomes available, which would then influence and adapt the collective understanding structure of the committee. If an unexpected event suddenly occurred from a previously unconnected field (like earthquakes or race relations), a new specialist machine could be brought in to the committee, and again, the collective understanding structure of the committee would grow and adapt. As the machines don't share the physical frailties of humans (fatigue, sickness), they can keep working on a problem to give updates on solutions when needed.

A committee of specialist machines actually has the potential of overtaking a rapidly evolving problem, not just keeping up with it. The committee of specialist machines could be formed across more fields than initially thought relevant. The collaboration of their active knowledge structures could be run faster than real time, so that they could determine the connections between the starting fields, if they are relevant to the problem and how a solution, influenced by them, might play out in the future. This doesn't require humans to come up with a prescriptive mathematical model of which factors influence the problem, or how they do so. The collaborative machines' model builds it from text. And if the circumstances change and a particular factor ceases to be relevant, then a prescriptive mathematical model doesn't need to be rebuilt. The collaborative machines' model will rebuild and adapt from updated text input, no matter how radical the change may be.

Can such a Machine Collaboration Be Ethical?

If each machine can see the basis for each other's contributions, it is likely to more nearly approach the goal of autonomy, which Kant says will lead to a moral outcome. An outcome which is based on fact and critiqued expectation is likely to more closely adhere to morality than one where large parts are opaque to many of the human collaborators.

Conclusion

The big, complex problems of this world require specialists from multiple disciplines to collaborate and through the synergy of their collaborations solutions can be reached that wouldn't otherwise have been possible. The collaboration of human specialists is difficult though, because they speak and think differently, using different terminology, have different objectives and get fatigued, like all humans do. A collaboration of specialist cognitive machines may overcome some of these difficulties because they can effectively "read each other's mind" and connect their understanding structure in one specialist domain to another. The way they collaborate may be modelled on a round table discussion of human specialists, with two big differences; when they collaborate, the process of clarifying the problem and thrashing out possible solutions would happen simultaneously, and secondly, their collaboration is not limited by time in the same way humans need lunchbreaks! The hope of collaborating specialist machines is to reach globally-optimal solutions to big, complex problems in shorter time frames, and in a manner that can quickly adapt as the problem rapidly evolves.

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