

MAAI - Meta-level Agents for Accelerated Impact

Yunfan Zhao

Harvard University, GE Healthcare
Bellevue, United States
yunfanzhao@fas.harvard.edu

Aparna Taneja

Google Deepmind
Bengaluru, India
aparnataneja@google.com

Niclas Boehmer

Harvard University, Hasso Plattner Institute
Potsdam, Germany
niclas.boehmer@hpi.de

Milind Tambe

Harvard University, Google Deepmind
Cambridge, United States
milind_tambe@harvard.edu

ABSTRACT

AI for social impact (AI4SI) offers significant potential for addressing complex societal challenges in areas such as public health, agriculture, education, conservation, and public safety. However, existing AI4SI research is often labor-intensive and resource-demanding, limiting its accessibility and scalability; the standard approach is to design a (base-level) system tailored to a specific AI4SI problem. We propose the development of a novel meta-level multi-agent system designed to accelerate the development of such base-level systems, thereby reducing the computational cost and the burden on social impact domain experts and AI researchers. Leveraging advancements in foundation models and large language models, our proposed approach focuses on resource allocation problems providing help across the full AI4SI pipeline from problem formulation over solution design to impact evaluation. We highlight the ethical considerations and challenges inherent in deploying such systems and emphasize the importance of a human-in-the-loop approach to ensure the responsible and effective application of AI systems.

KEYWORDS

Social impact, Foundation Models, Multiagent Systems

1 INTRODUCTION

Artificial intelligence (AI) for social impact (AI4SI), which focuses on leveraging AI to address societal issues, has gained traction in both academia and industry [14, 20, 30, 45, 68]. With advancements in AI and multi-agent systems, there is an opportunity to apply these technologies to complex problems in areas like public safety, wildlife conservation, and public health [29, 44, 50, 86]. Previously, AI4SI research has been very labor-intensive, as it is oftentimes necessary to develop customized approaches going beyond conventional methods to address the challenges characteristic to these domains such as low resources and noisy or scarce data. This limits the overall impact of AI4SI research, as every individual effort requires non-trivial time, expertise, and financial investment. We envision the formation of a new approach to AI4SI which is less labor-intensive, customizable by non-experts, and can thus be made more widely available. We believe promising progress can be made on this vision by employing recent methodological advancements in computer science research, tapping into a substantial currently unleveraged potential.

In this paper, we will use resource allocation problems, which often arise in AI4SI domains [4, 5, 22, 49, 62, 68, 86, 125] as our running example, yet our general ideas also apply more broadly. Some examples of previously studied resource allocation problems in AI4SI include strategically scheduling patrols in protected conservation areas [32, 34, 36, 108] and distributing scarce healthcare resources to optimize people’s health outcomes [12, 60, 76, 84, 125].

We envision a meta-level multi-agent system that helps us accelerate the development of base-level systems, which tackle specific AI4SI problems. The meta-level system would help non-profits and AI researchers in social impact domains leverage AI without having to invest significant amounts of labor and resources to build a tailored base-level system from scratch. Our envisioned system leverages foundation models, which are typically developed by pretraining on available datasets, and can be used on different downstream tasks or new challenges [8, 13, 47, 85, 124]. Our proposed system involves: (i) using LLM based meta-level agents to communicate with decision makers in human language to understand the problem from the perspective of decision-makers; (ii) employing meta-level agents and foundation models for AI4SI problems to design base-level systems for AI4SI problems; and (iii) using meta-level agents for field-testing solutions to validate their impact.

Importantly, instead of taking over the AI4SI pipeline, the meta-level system will accelerate the process, improve generalization, and enable thorough evaluation, with human-in-the-loop required in each part of the system. We will discuss and highlight major challenges and our vision for each phase of this system, emphasizing the multi-agent aspect. We also discuss ethics and fairness aspects.

The current era of foundation models has led to contemplation on the challenges and opportunities that such models may offer in multiple areas, from medical AI [61] to autonomous supply chains [112], autonomous mining [53], and robotics [88]. In comparison with these previous works, this paper focuses on the use of foundation models in AI4SI. Moreover, even within AI4SI, we exemplarily focus on optimizing the allocation of limited resources, providing an analysis of challenges in a specific aspect of AI4SI. Furthermore, in contrast to previous work, we focus more on foundation-model-based agents at the meta-level, to assist base-level systems that optimize these limited resources, rather than replacing the base-level system entirely. This enables existing well-developed resource optimization tools to be brought to bear on relevant challenges as

required, allowing instead the foundation models to configure the tools as needed.

2 PRELIMINARIES

We formally define the key concepts of meta-level and base-level systems, which we will refer to throughout this work.

DEFINITION 1 (META-LEVEL AND BASE-LEVEL SYSTEMS). *A base-level AI4SI system is the actual deployed system that will solve the problem on the ground. A meta-level system helps us accelerate the development of a base-level system or accelerate its modification as needed for a new objective.*

Notably, a meta-level system does not actually solve an AI4SI problem. A meta-level system may involve several meta-level agents, each responsible for different tasks in the development of the base-level system, which may interact with each other. In the context of the use cases we are focusing on in this paper, the base system itself will be a multi-agent system or one that models multi-agent interactions such as a social network. The base-level agents present in the base-level system are defined as follows:

DEFINITION 2 (BASE-LEVEL AGENTS). *In the base-level system, the base-level agents model or serve as abstract representations of individuals or entities in the real-world.*

Whereas the idea of a meta-level architecture has been proposed in agent architectures, there the idea is to directly assist agents in their immediate problem solving [19, 33, 71, 94]. In our work, the meta-level refers to deciding which agents and how many to select, how to evaluate their performance, and other such tasks. Another difference is that at least as conceived now, our meta-agents are focused on assisting humans in building base-level agents.

Another key concept we will frequently refer to is meta-level agents and hence the name MAAI for our proposed framework (meta-level agents for accelerated impact).

DEFINITION 3 (FOUNDATION-MODEL-BASED AGENTS (META-LEVEL AGENTS)). *In the meta-level system, we use meta-level agents that employ foundation models including LLMs. We will refer to these agents as Meta-level agents*

REMARK 1. *In this work, we focus on social impact and we address challenges unique to social impact domains, such as limited resources and high-stake decision making.*

An AI4SI pipeline typically involves three phases [14, 68]:

Formulate the problem Identify how to best represent or model the real-world entities and multiple stakeholders involved in the on-the-ground problem, along with their constraints and objectives. For example, the real-world entities may include individuals enrolled in social welfare programs and decision-makers such as non-profit program managers. Previously, this effort was largely manual and involved multiple parties, including nonprofits and AI researchers [23, 77, 82].

Design solution method Identify appropriate solution methods and adapt them to design the base-level system. Previously, this process was largely manual in terms of researcher efforts to tailor advances in AI algorithms to the specific application scenarios. The adaptation to different application scenarios was also largely manual [10, 24, 65, 89, 98, 107].

Evaluation, refinement, and deployment Testing, improving, and deploying solutions has typically been done manually, adding to the workload of researchers and even more importantly to that of resource-constraint NGO workers [86].

Notably, each step in the AI4SI pipeline poses its own challenges [79], implying that AI4SI work often requires substantially more effort than pure AI algorithmic improvement research. Specifically, formulating the problem and collecting detailed information (e.g. potential decisions available and their impact on each of the individuals) can be time-consuming and expensive [72]. Moreover, designing solution methods can require significant time from AI experts and social impact domain experts [82], who must work together to devise a tailored solution method for every application scenario. Thorough testing and evaluation before deployment often require substantial manual effort, as detailed simulation studies are often required (e.g. by regulations or as precautionary measures) [7], and AI experts typically manually design each simulation study from scratch.

For our running example, we consider allocating limited interventions (specifically live service calls made by health workers) in ARMMAN, which is a non-profit in India focusing on improving health awareness for expectant and new mothers [75, 124]. Their health workers make service calls to boost the engagement of mothers enrolled in their health information program. They have shown that AI powered solutions can reduce engagement drops by about 30% in real-world deployment [59, 89].

3 FORMULATING THE PROBLEM

In this phase, we discuss how to formulate an AI4SI problem. Existing works require researchers and human experts in AI to talk to collaborating non-profit organizations to understand who makes the decisions within a problem and gather key information on the agents such as demographics [86, 97]. This process is expensive and labor-intensive, and non-profits may not have AI-trained staff to assist with this, making it difficult to ensure that AI solutions are accurately tailored to the complexities of the real-world problem. Thus, previous works often require AI researchers to have numerous rounds of discussions with non-profits and arrange a field trip to speak with key stakeholders in social good programs. Whereas these discussions are fundamental to AI4SI, some of the work oriented toward formulating the right base-level model is repetitive. To accelerate this work we propose the following vision:

VISION 1. *Employ Meta-level agents to (i) identify the base-level agents involved, (ii) find an adequate formal description for the setting (e.g. as a Markov Decision Process), and (iii) define key components of the settings (e.g. state space, action space, and reward function in a MDP).*

The Meta-level agents may use large language models to communicate with a partnering non-profit to formulate the social challenge as an AI problem and to understand who makes the decisions within a problem. The world knowledge of LLMs may help the Meta-level agent uncover confounding variables and undocumented information [38, 39, 43, 51, 74, 87, 100, 111]. The Meta-level agent should determine what information the individuals or entities in the real-world have to guide their decisions. The Meta-level

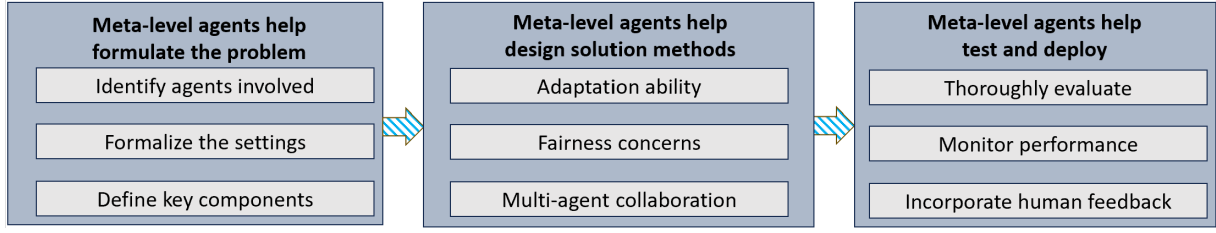


Figure 1: Overview of our proposed AI for social impact (AI4SI) workflow. The three key phases, formulating the problem, designing the solution methods, and testing and deployment, are discussed in Sections 3, 4, and 5 respectively.

agent should then define base-level agents to model the individuals or entities and make proper assumptions about the information available to them.

The Meta-level agent may gather data from past interactions, including the effects of actions, and observed costs or rewards, and interactions between agents [28, 70, 126]. The Meta-level agent, potentially LLM-based, could communicate directly with beneficiaries enrolled in non-profit’s program in their native language to gain a clearer perspective and would not have time constraints.

RUNNING EXAMPLE 1. *In ARMMAN, the base-level agents represent beneficiaries enrolled, and the state and action space correspond to beneficiaries’ engagement levels and possible schedules of service calls, respectively. The Meta-level agent should have conversations with domain experts in ARMMAN to find out that one way to approach this application scenario is to model beneficiaries as agents that follow Markov Decision Processes. After that, the Meta-level agent should define the state space, action space, and other key parts of the MDP.*

4 DESIGNING SOLUTION METHODS

In this phase, we elaborate on how to design a solution method for AI4SI problems. Existing approaches often require manually designing solution methods tailored to each application scenario [2, 56, 57, 99, 106, 113, 128]. This approach fails to easily adapt to new application scenarios or knowledge and data from previous application scenarios, motivating the development of foundation models to accelerate solution approaches for problems in AI4SI. **Besides adaptation ability, other aspects that are of particular importance when designing solution methods in AI4SI problems include ethics, fairness, and collaboration among base-level agents. We will motivate each of these aspects and propose our visions to address them.**

Adaptation is crucial in AI for social impact domains due to the dynamic and evolving nature of these environments. Social issues are often complex and multifaceted, with priorities evolving overtime [7, 11, 21, 64, 91, 93, 114]. A foundation model for resource allocation could accelerate developing solutions for different application scenarios without incurring repeated development costs, making them more affordable and accessible to low-resource communities [13, 15, 119, 124]. For example, a foundation model designed to analyze medical data can be adapted to different diseases, health conditions, or populations, improving health outcomes on a larger scale [52]. Based on advances in foundation models and adaptation, we propose the following vision:

VISION 2. *Build a foundation model for resource allocation problems in AI4SI domains that can be adapted to and finetuned on specific application scenarios. For each new AI4SI application scenario, employ a Meta-level agent to leverage the foundation model and provide solution methods.*

RUNNING EXAMPLE 2. *A concrete example of foundation model for resource allocations tasks is given by Zhao et al. [125], who develop a pretrained restless bandit model that can be finetuned on various resource allocation application scenarios that ARMMAN may encounter. Currently, the application scenarios have different number of base-level agents and different amounts of distribution shifts. Here, our research idea is to start with such a foundation model and allow an Meta-level agent to adapt and specialize it to newer scenarios that may involve bigger changes than just differences in numbers of base-level agents. This could include new application scenarios that may need a change of the states and actions in the restless bandit model.*

To address the inherent complexity of social challenges, we may also use Meta-level agents in the form of Large Language Model (LLM) to process and understand human instructions, queries, and feedback from stakeholders to alter the priorities within the resource allocation process [55, 81, 95, 96, 101, 110, 120]. For example, in the ARMMAN domain, a program manager may suggest prioritizing a specific segment of the underserved population such as those older in age, which an LLM could interpret and accordingly adjust the restless bandit resource allocation model by changing its reward function [7, 83].

Besides the adaptation aspect, fostering efficient collaboration among multiple base-level agents plays an important role in AI4SI research. Recall that a base-level agent serves as an abstract representation of an individual or an entity in the real-world. In some problems, multiple base-level agents may collectively plan to counter an adversary such as wildlife poacher or terrorists [36, 78, 105]. In other problems, multiple base-level agents may communicate to mitigate the impact of data errors, which frequently arise in real-world situations due to factors such as inconsistent data collection methods and deliberate noise introduced for differential privacy [25, 26, 66, 115, 116, 127].

However, previous works in AI4SI often require human experts in AI to manually craft ways of collaboration among base-level agents for specific AI4SI domains. An Meta-level agent can help with this process to accelerate AI for social impact work:

VISION 3. *The Meta-level agent, when designing solution methods for base-level systems, should design effective communication channels*

and strategies for base-level agents. Specifically, these channels should allow base-level agents to learn from each other's experience and to improve decision-making.

Although the above vision on developing collaboration may appear to be straightforward for human-AI experts crafting solution methods, it is not easy for Meta-level agents to figure out due to complex relationships between base-level agents [46, 54, 69, 90, 92, 123]. The Meta-level agent may use the world knowledge of LLMs to understand which communications can be potentially useful and should be included in the design of solution methods [16, 117]. Here a communication channel may be that an individual or entity talks to another via cellular network or other infrastructure in place.

4.1 Ethics and Fairness

In high-stakes resource allocation scenarios like healthcare, authorities frequently prioritize certain groups based on sensitive attributes, aiming to address the needs of those most disadvantaged [1, 84, 103]. For example, governments may mandate non-discrimination based on sensitive attributes, while non-profits may prioritize low-income groups. Given the importance of fairness in base-level system design and the solution method's tangible impact on people's lives, we propose the following idea:

VISION 4. *Ensure that the Meta-level agent recommends the design of a base-level system that does not discriminate against any subpopulation or result in unfavorable outcomes for under-privileged groups.*

When accelerating the design of base-level systems, the Meta-level agent should ensure fairness guarantees or fairness checks are in place. This can be done by explicitly incorporating fairness in designing base-level systems for social impact applications [84, 121]. However, this added complexity is difficult for Meta-level agents to handle, due to the fact that AI may not easily understand demographic information available in text or abstract fairness concepts potentially based on demographics.

RUNNING EXAMPLE 3. *In ARMMAN a concrete example of fairness constraints is the enforcement of non-discrimination based on sensitive attributes and the prioritization of low-income and low-education groups to reduce socio-economic disparities. In the ARMMAN context, demographic information for enrolled beneficiaries are available. When designing a base-level system, the Meta-level agent could enforce fairness constraints such as that each beneficiary must receive a sufficient amount of resources within some time. Additionally, the Meta-level agent should prioritize underprivileged groups by explicitly optimizing a fairness objective (e.g. Max Nash Welfare or Maximin Reward) in the solution method.*

5 TESTING AND DEPLOYMENT

In this phase, we explain how to thoroughly evaluate and deploy AI models for social impact domains. We use Meta-level agents to improve model testing and facilitate real-world deployment.

Deploying an AI model in real-world social impact domains without sufficient simulation studies may result in poor decision-making on crucial public resources. Thus, thoroughly testing and evaluating AI algorithms or trained models is an important aspect

of accelerating AI for social impact. Based on above, we propose the following research idea:

VISION 5. *Employ Meta-level agents, based on LLMs, to simulate agents' behaviors. Here we wish to build a powerful simulator that serves as a good proxy of real-world deployment environment and can effectively evaluate the performance of trained models.*

LLM based simulators have recently received great interest, and there is demonstrated success in using LLMs to simulate human behaviors in fields including education, healthcare, and social sciences [3, 17, 58, 73, 80, 102, 109, 118]. To build such a LLM simulator / evaluator for AI4SI problems, we should represent observations and possible decisions in a way that the LLM can understand, and potentially use textual descriptions combined with structured data, to help the LLM simulator generate contextually appropriate (e.g. suitable for the domain) individual behaviors. Furthermore, textual descriptions on individual's characteristics, such as demographic information (age, gender, geographical location, etc) may help LLMs to better understand how individuals' condition would evolve over time. For a particular AI4SI problem, we may need to finetune LLMs on historical data collected to better simulate the individual's trajectories.

RUNNING EXAMPLE 4. *In the ARMMAN application, we need to thoroughly test algorithms before real-world deployment. An Meta-level agent can employ LLMs to perform agent-based simulations to evaluate learning algorithms [37, 63], or use cognitive models to augment ML based evaluation approaches [35, 75].*

Having discussed evaluation before real-world deployment, we now move on to challenges in the deployment. During the deployment of AI models, there can be shifts in the user base or shifts in people's behaviors [6, 27, 41, 42]. Different from adaptation ability taken into account during model development and training, distribution shifts in testing can be unexpected and the need to handle these shifts can be urgent. This brings the next research idea:

VISION 6. *Have an Meta-level agent that could (i) involve human-in-the-loop and implement real-time monitoring to track model performance and detect shifts in user behavior or data distribution; (ii) use feedback from either human or AI to adjust the model (e.g. enhance model fairness when there are unexpected distribution shifts).*

Specifically, we may use a feedback loop to gather data on model predictions and user interactions, allowing for prompt detection of shifts in behavior [7, 9, 104]. Once substantial shifts in user behaviors are detected, we could then involve human experts, potentially from partnering non-profit organizations, to review and provide feedback on model predictions and decisions. This feedback can then be used to guide model adjustments and improve its response to distribution changes. We may retrain or finetune the model using newly collected data, potentially weighting recent data more to better align with current trends and user behavior [13, 18, 31, 40, 48, 67, 122].

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