

An Automata-Theoretic View of Agent Coalitions

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Abstract

We find similarities between the agents world and the automata theory world, and take the position that proven automata theory results can be adapted to the formation, adaptation and maintenance of agent coalitions. We look at complex problems as decomposable into more easily solved sub-problems, and find that realizing structures can be found or adapted to behave as specified. This is the case for finite state devices found in theory, and for agent coalitions solving complex problem components on the web. We illustrate these concepts with some discussion of a Travel Assistant and describe some applications and related results of other researchers.

Introduction

We find many similarities between the agents world and the automata theory world, and so our position is that proven automata theory results can be adapted to selecting and configuring groups of agents.

For example, in our automata theory world, any solvable problem will be the “behavior” of some finite state system or “device”. Device or system components will be a collection of “states” connected together into sub-devices or subsystems that correspond to solutions to specific sub-problems. In the agents world the agents solving sub-problems correspond to those automata “states”, and their interactions may be viewed as if they were automata state-to-state transitions. When a group of agents solves a particular problem or completes a particular process it as if, in an automaton, it has reached a “final state”.

As we extend the analogy we believe we can adapt some important automata theory to improve problem-solving agent design. E.g., based on the techniques for finding minimal automata to realize specific behaviors, we should be able to find compositions of groups of agents that will solve problems in an optimal way.

Here we describe our comparisons between automata and interacting collections of agents, including the coalitions that are formed as necessary to solve sub-problems. We illustrate our concepts with some applications to real world processes, and describe related work of others applying theory to problems of the real and agents world.

Our Automata Theory World

Grounded in automata theory we tend to think of problems as solvable (or approximately solvable) when their solutions can be (perhaps approximately) represented by some variety of finite “system” or “device”. A successful problem solution becomes the *specified behavior* of the system/device and the system/device a behavioral realization if it achieves that *specified behavioral goal*. To illustrate this less abstractly, we might consider the problem of planning and booking a trip to AAAI-04 in San Jose and the finite “device” the discrete (not necessarily sequential) steps and procedures that are collectively involved in arranging the travel. When the travel is successfully arranged that specified behavioral goal is achieved and the future-trip behavior is realized.

Of course there may be many successful plans, many possible collections of planning procedures, plans that are optimal according to some established criteria, or plans that succeed only sometimes (but are really efficient when they do). Flexibility may be needed, and adaptiveness, too. E.g., we may learn there is a train from Salinas to San Jose that would change the original plan to travel by bus, but would maintain the original behavioral goal. *You* might want to use our “Travel Assistant” collection of procedures to arrange your trip from Princeton to AAAI-04, and *we* might also wish to arrange a trip to ICSE in Edinburgh, each retaining the same “behavioral domain” of trip-planning, while changing the specified behavioral goal. Changing the goal would necessitate some adaptation of the procedures collectively invoked to arrange the trip(s).

Finally, today we may use a credit-card-charging procedure as part of our Travel Assistant to reserve the cheapest-and-most-convenient hotel room in Edinburgh. Tomorrow we might use the same credit-card-charging procedure as part of a Shopping Assistant, to select and purchase the cheapest-and-most-nutritious cornflakes at Safeway. The travel-behavioral domain and the shopping-behavioral domain have a non-empty intersection, and solving travel or shopping problems may invoke some identical or similar procedures to achieve their respective behavioral goals.

In our automata theory world, we look at complex problems as decomposable into sub-problems that may be more easily solved (Fass 2002), as we have done above,

and we look at relationships between a specified behavior and a realizing system/device. Thus to fulfill the specified behavioral goal of arranging our trip to AAAI-04, we would determine the problem's sub-problem components (arranging transportation, reserving a place to stay, pre-registering for the conference, ...). We would then match each sub-problem with one or more fulfilling processes or procedures that we know to exist and, once done, the entire problem would be solved. This approach effectively collects the necessary fulfilling processes and procedures into a structured system or device. Its components correspond to the processes and procedures, and its structure is determined by how they interact. Solving the entire problem takes this system/device to a fulfilling final state. Tomorrow we may find a new or better process or procedure to solve some sub-problem(s) and adapt the structure to accommodate it, producing the same ultimate problem solution in a differently-structured way. We may also select some components for use in a different system/device to solve a different problem (e.g. the Travel Assistant vs. the Shopping Assistant), in which case both the specified behavioral goal and the realizing "device" may change.

Where Are the Agents and the Coalitions?

Now suppose the sub-problem-solving component processes and procedures described above were autonomous software entities dwelling within a particular host or, perhaps, distributed throughout the web. We would call them *agents*. A universe of agents under consideration, to us, would be a *multiagent system*. And, from a universe of existing agents some might be selected and configured/connected to form a "device" or system that solves particular problems or behaves collectively in a pre-specified way (e.g., as part of a software Travel Assistant). We would call that a *coalition*.

To us, an *agent coalition* is a collection of agents grouped, as needed, to interact and effect a specific process or solve specific problems. The coalition may be maintained as long as it is of use. It may be adapted if and when an alternative member is found (e.g., perhaps eliminating an inefficient available processor when one more efficient becomes known). Coalitions may merge if they are found to solve different aspects of the same problems, and this could facilitate and improve interactions among members. Thus a coalition might become a component in a larger coalition. (E.g., if we always and only compute metric conversions within a travel domain, we may as well make our Metric Converter part of our Travel Assistant.)

We do not consider issues of how coalitions are found from the agents' perspective, e.g., by persuasion or argumentative negotiations (Soh and Tsatsoulis 2002). We consider them solely from the automata theorist's

perspective, i.e., that a structure can be found to behave as specified. Thus, we view agent coalitions as multi-component systems whose individual components and subsystems may be configured to achieve specified behavioral goals. A collection of agents might be configured dynamically to produce a specified goal-directed result, and dynamically reconfigured to adapt when a different behavioral goal is specified. E.g., planning a trip from Carmel to AAAI-04 by bus or by car could lead the Travel Assistant to the same final state by different paths. Planning a trip from Princeton to AAAI-04 or from Carmel to Edinburgh could necessitate modifications, perhaps producing Travel Assistant and Travel Assistant . Each individual agent may have its own capabilities and effect some task that may or may not fulfill a component aspect of a specification. But composing individual agents into an appropriate interacting, communicating structure produces a *coalition* that can realize a specified behavior or adapt to changing behavioral goals.

Forming and maintaining agent coalitions is much like the behavioral analysis and goal-directed synthesis problems of automata theory.

Our Analysis and Synthesis Research

We first considered goal-directed behavioral modeling as an automata theory problem to be solved within the scope of inductive inference and computational learning. The purpose was to represent infinite behavioral possibilities by some finite (learnable) means. We investigated representation of complex systems to establish relationships between behavior and structure. As we indicated above, we strove to determine the structural components that would be necessary in a behavioral model, and interactions of components that could realize a specified behavioral goal. In highly constrained theoretical problems we showed that classes of behavioral elements merged into disjoint categories (congruence classes based on behavioral indistinguishability). The categories corresponded to components necessary in a completely specified behavioral model.

As a result we could construct a behavioral model based on how we did and did not wish it to behave. A system of components so constructed could "grow" as behavioral specifications expanded or could adapt as a behavioral goal changed. We found that the behavior of an approximating system could be monitored and adequately tested, with sufficient theoretical constraints. Design defects could be detected and repaired, structure adapted and, as a result, improved. We have found many applications of our automata-based theory to problems solved in the agents world [some of which are described in (Fass 2002, 2003)], such as training of a reactive voice-recognition agent, or error-detection and correction of an e-commerce airline

reservation system component residing on the web. With little modification of focus, we find applications to the agent coalitions world.

Our concept of determining behavioral classes to be realized by components is very closely related to determining and forming agent coalitions. Many practical problems may be solved by decomposing a behavioral goal into subgoals to be realized by agents in a coalition: autonomously, collaboratively or, perhaps, competitively as may be deemed fit. Our determination of component interaction (to realize a behavioral goal) is closely related to techniques of link analysis, where masses of data and observed behaviors are analyzed to discover patterns of activities and interactions among the actors. From the analysis, a predictive model is produced to describe future interactions and events. The model may indicate necessary corrective changes or improvements to the entities analyzed. Such processes are often employed to discover and perhaps alter social relationships among *humans* in coalitions. These techniques can obviously be modified to discover links defining or within agent coalitions, facilitating and enabling agents to communicate and interact. The use of language games for automated learning and agent-human or agent-agent interactions are reviewed in (Fass 2004a), where some research in establishing agents' communication channels is described.

The most comprehensive example of a dynamic, adaptive and emergent coalitional structure of which we are aware is the potential structure of the Semantic Web. We believe its development is relevant to all topics of Forming and Maintaining Coalitions in Adaptive Multiagent Systems. Some of its semantic link discovery, language-related processes and navigating agents are discussed in (Fass 2004a). Due to the dynamic nature of the web, the plethora of possible services, the complexity of site interoperability, and so forth, we can see outstanding opportunities for advancing techniques for the formation, adaptation and maintenance of agent coalitions, and the resultant related issues that may arise. For example, some of the security and trust problems related to web services and agents, and their interactions with today's users, are described in (Fass 2004b). Both (Alonso 2002) and (Bradshaw, Cabri and Montanari 2003) indicate that security and trust problems that might be resolved for users of individual agents become extremely complex when there are agent-agent interactions. They become more so when the agents are each subject to their own local rules while interacting globally across the web. Still, we believe coalitions of agents existing on the Semantic Web may be constructed to solve diverse user problems, and be maintained or reconfigured to function in a secure and trustworthy fashion as the agents, the web and the collection of users may expand and change.

Related Work

Our view of coalitions is much like the (Brooks and Durfee 2002) concept of congregations. They self-organize multiagent systems into smaller groups interacting locally to solve problems together. We find this similar to our merger of behavioral domain elements into congruence classes of like-behaving elements, represented by components in a behavioral model. Coordinating agents to achieve a common goal is also considered by (Guestrin, Venkataraman and Koller 2002). There maximizing joint utility of agents is investigated, just as we propose to optimize the coalition that achieves a specified behavioral goal.

Partitioning problems into simpler component problems to be dealt with by specialist agents within a multiagent system is described by (Alonso 2002), who reports this reduces time complexities in the system. He also emphasizes issues of flexibility and adaptiveness. Iterative adaptations of coalitions are described by (Soh and Tsatsoulis 2002), starting with a non-optimal coalition and refining it until it is finalized. This is much like the automata theory concept of iteratively refining an initial behavioral partition to construct a finalized optimal (e.g., minimal) behavioral realization.

That these results can actually be applied is illustrated by the implemented e-commerce examples described in (Greenwald, Jennings and Stone 2003) and work cited and proposed throughout (Tumer and Smith 2002). Implemented deductively-defined agent interactions are described by (Waldinger 2002), whose work involves construction of agent-based processors to solve specific classes of problems. The necessary agents are located on the web and deductively interact as warranted, even though they were never originally intended to work together. (Waldinger's examples include a conflict-resolving scheduler and a system that processes geographical queries.) This work reassures us that there are aspects of the Semantic Web that will surely succeed. We also interpret it as a successful approach to forming agent coalitions.

Conclusions

Our overall position is that utilizing techniques of automata theory, as we have described, we can locate the necessary components of agent coalitions and facilitate their interactions, realizing specified behavioral goals. We can adapt them as behavioral goals change (perhaps locating new components; perhaps changing patterns of interaction). We can improve structure until an optimal coalition, relative to the behavioral goal, is formed. And we know from automata theory that for any realizable behavioral goal an optimal coalition will exist.

We leave it to the developers of multiagent systems to implement the theory and provide the means by which these coalitions and optimal coalitions actually may be formed and maintained. We provide the theory.

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