An Emergence Approach to Behavior Convention in Agent Group through Propagation of Plans

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Abstract

This paper analyzes the effect of behavior conventions in agent groups. An emergence approach to the convention formation through the propagation and evaluation of plans is presented, which is based on the analysis for the convention effect to the utility of a single agent. This approach is able to generate complex conventions and suited to open environments. It is also jibe with the autonomy of agents. A quantitative model for the propagation of conventions is given out, with which the disseminating rate of convention is studied.

Introduction

With the development of multiagent systems(MAS), the study for coordinating technology during agent interactions has evolved from the on-the-spot reciprocal joint planning to establishing behavior conventions of agent groups in advance. When autonomous agents interact with each other, they must form joint plans assuring their actions to coordinate with the others or not to conflict with others. The generation of a joint plan needs communication and computation. If agents interact in real-time environment, the planning cost may harm the real-time respondent speed. To reduce the consummation of computational and communicative resources and speed up the responsiveness, behavior conventions are designed to guide the interactive actions of agents.

A behavior convention is a rule to make selection among the possible action strategies when agents interact. The agents abiding by a convention need not make joint plan again when they interact in certain situations, but just take actions directly according to the prescription of the convention. This reduces the expenditure of joint planning. The rationality of agent actions should be ensured by the convention when without planning, so how to form a rational convention in agent group becomes the key to this approach.

The study of MAS pays special attention to the autonomous agent decision-making, hoping to get the rationality of the whole system from the rational behaviors of single agent. This paper steps along this line, but emphasizes that the propagation of knowledge among agents plays an important role in establishing global rationality and forming conventions. This approach is still based on the autonomy and self-interest assumption about agents, but it can lead agents naturally to a society of agents, not only a loose collection of agents. An emergence approach to convention formation based on the propagation and evaluation of plans is presented, with the quantitative model for the propagation process and the calculation of the propagation rate.

Behavior Convention in Agent Group

There is yet no any uniformed definition to the behavior convention in agent group. Y.Shoham calls it social law, which is a rule to define actions forbidden in certain situations (Shoham & Tennenholtz 1992). A.Walker's convention is the template for agents to select their actions (Walker & Wooldridge 1995). J.Kittock's convention is the rule to make common selection among many possible strategies when accomplishing certain tasks (Kittock 1994).

In this paper, the convention is a plan for multiagent actions in certain situations. A convention defines the situations, called convention scene, in which it is suited. In convention scene, agent can act according to the prescribed action sequence in the convention, and the convention will generally ensure the actions' accomplishment. In some extent, a convention is similar to a script. A simple definition to convention is shown as follows:

Convention := { ENV, { ROLE, ACTION-SEQUENCE}}, in which ENV : = { state(env) | state() is the predicate about the state variables of the environment }, ROLE : = { pos(agent) | pos() is the predicate about the situation of agent in the environment}, ACTION-

SEQUENCE : = < a1, a2, ..., am > is the action sequence for agent to take when the agent is in the role of ROLE.

The above definition gives only some basic components necessary to a convention, and the concrete form should be decided by the knowledge representation and inference mechanism in specific MAS.

The convention is an expansion to the joint plan generated in the interaction locale. Joint plan assigns actions for every agent, while group convention includes the description of joint plan locale in ENV to guarantee the effectiveness of convention, and the actions of the individual agents participating in the plan correspond to {ROLE, ACTION-SEQUENCE} in the convention. The similar form of convention with the plans in the agent ordinary actions bases our emergence approach.

After the agent accepts a convention, it must act according to the ACTION-SEQUENCE correspondent to the satisfied ROLE when its environment satisfies ENV. Represent this rule with predicates as follows:

Accept(Convention, t) =>
 (State(Env, t') |- Env(Convention) =>
  (Pos(A,t') |- Role(Convention,r) =>
   Action-Plan(A,t'') =
Apply(Action_Sequence(Convention,r), Env))

The computational model of the agent behavior under a convention is out of the discussing range, so here is only a preliminary description.

Emergence of Convention

The conventions can be designed manually when the multiagent system is constructed (Ephrati, Pollack & Ur 1995) (Goldman & Rosenschein 1994), or be generated when the system is running. The convention designed by the system designer can be modulated to the characteristics of the system, so its efficiency could be high, and could be analyzed in advance. In other side, the pre-designed conventions cannot adapt to the variation of the system structure and the environment, therefore its utilization is limited. The conventions generated when the system is running could adjust the agent behavior according to the current state of the system and the environment, and is flexible. The generation of conventions is classified into two types. One is assigning the agents to certain roles by a central controlling agent before beginning to perform a task, so the convention for every agent is established. Another one is evolving out a convention from the interactions among the agents when all the agents are free to act according its goal. The central controlling mechanism has spontaneous weakness in MAS, for the basic assumption for MAS is the autonomy of agents in MAS. The central controlling mechanism has defects in the system efficiency, fault-tolerance and security. The evolving approach to the generation of conventions needs no central control, and is flexible and easy to implement.

The studies about the emergence of conventions all suppose that there are several convention candidates possible to admit in the system, and the emergence is just the convergence to a common selection of global strategy through the local decision and interaction of agents. This kind of emergence is hard to adapt to open and dynamic system. In an open and dynamic system, those strategies assigned by the designer in advance cannot anticipate all the possible variations, and cannot guide the agents' actions correctly in a changed environment. An effective convention should be generated by the system itself in running, and reflect the environmental features, requirements and the system's running history.

The emergence of convention in open and dynamic environments is more than the generation of convention. A convention can play the role of adjusting the group member behavior only after it is accepted by numerous agents in the group. The problem in temporal studies is that the spread of conventions does not take the autonomy of agents into account, and not consider the agent's self-interested nature. This is not compatible with the trends of emphasizing the agent's autonomy in MAS research. In autonomous agent system, the spread of a convention must be based on the utility evaluation by agent. If a convention is one-sided and be beneficial only to certain agents, those agents harmed by it will not accept it.

The key to an effective mechanism in autonomous and self-interested MAS is whether it can bring apparent and expected revenue to most agents. Each individual understands that cooperation is beneficial from the long term and the whole view point, but in the specific interactive scene, agent cannot get global information, and must make decision only with local information and goal. The real decision is based mostly on the agent's own goal. So only if the agent can compute out the revenue from its local view, the convention mechanism can work stablely, and the convention can propagate from small part of the group to the whole system. This is the key to emergence. No matter whether the agents own strong intelligence or not, even they are stimulus-reaction objects without basic intelligence, it is still possible for the agent group to emerge into convention. The construction and propagation of emergent convention must be based on the ordinary actions of agent. That is the only one premise for effective emergence.

Self-construction of convention

The emergence of convention will be explained with the following example. This situation involves only the interaction between two agents, but the principle for emergence explained here is not limited in the two-sided joint planning. In those situations where there are three or more participants, this approach can also lead to the emergence of behavior convention. This approach focuses on the roles of generated plans as the candidates for interaction conventions, and the agents' behavior in such situations. As long as the plan situation can be generalized and the roles of agents in the situation can be recognized in a situation recurrence, this method can be applied to generate emergence.

In a situation of planning for mobile robots, there is only one channel AB between area 1 and 2, and the channel can only pass one robot. See Figure 1.The robots' view range is limited, and is only half of the channel length L. If a robot enters the channel, it cannot see if there is another robot in the other head of the channel. If two robots enter the channel simultaneously from two sides, they would have been in the middle of the channel when they meet. Now they must interact and form a joint plan. The plan result is that the robot nearer with the exit will move back and the other one move forward. This plan can be converted to convention as follows:

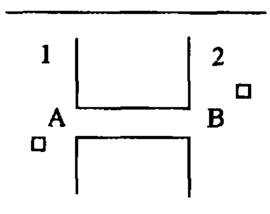

Figure 1. Mobile Robots Planning

IF the distance from the entry, l, satisfy $l < L/4$,
L is the length of channel
THEN move back
ELSE IF $l > L/4$ THEN move forward.

The distance from entry is the distance that the robot has moved since it enters this channel. This environmental parameter can easily be acquired by a path meter, and is a kind of information locally available. This convention involves only local information, but leads to global optimal solution without complex interaction and communication. The agents can get revenue from this convention such as reducing the communication and decreasing the total cost for multiple interactions.

The detailed process of emergence in the above example is as follows:

Distance(X, Y) is defined as the distance from robot X to its entry point Y. V(X) is defined as the moving speed of robot X. A differential expression dx/dt is used as the moving plan to indicate whether a robot is going to move forward or back. If $dx/dt > 0$, the robot is going to move forward.

Two agents are A1 and A2 respectively. When they find each other, the situation is: Distance(A1, A) = L/8, Distance(A2,B) = 3L/8, the moving speed is V(A1) = V(A2) = L/8.

A1 will generate Plan1:

$d(\text{Distance}(A1,A))/dt > 0$ (while Distance(A1,A) $\leqslant L$)
$d(\text{Distance}(A2,B))/dt < 0$ (while Distance(A2,B) $\geqslant 0$).

After evaluating this plan, the time for A1 to arrive at the exit B is 7, and the time for A2 to arrive at A is 7 + L/V2. The result is represented as T = (7, 7 + L / V2).

A2 will generate Plan2:

$d(\text{Distance}(A1,A))/dt < 0$ (while Distance(A1,A) $\geqslant 0$).
$d(\text{Distance}(A2,B))/dt > 0$ (while Distance(A2,B) $\leqslant L$).

After evaluating the plan, the time for A2 to arrive at A is 5, and the time for A1 to arrive at B is 5 + L / V1. This result is represented as T = (5 + L / V1, 5).

There is discrepancy between these two plans. Each agent supposes itself to act according to the other's plan, then gets the result:

Plan1: T1 = (7,15), Plan2: T2 = (13,5).

After exchanging the plan result, the agents should select Plan2 in the criteria of global optimism.

The generalization of the above situation and plan can be made with several ways, the simplest one of which is to transform the constant parameter to variable, like the inductive inference. When applied to this example, A1 and A2 are replaced respectively by variable X1 and X2, and A and B are substituted with TX1 and TX2. The generalized plan is as follows:

Situation:
D1= Distance(X1, TX1) = L/8,
D2= Distance(X2,TX2) = 3L/8,
V(X1) = V(X2).

Plan:
$d(D1) / dt < 0$ (while $D1 \geqslant 0$)
$d(D2) / dt > 0$ (while $D2 \leqslant L$)

The advanced generalization need make inference about the situation and determine in which situations Plan2 is better than Plan1. The time cost by Plan1 is ((L-D2) / V2, (L-D2) / V2 + L / V1), and the time for Plan2 is ((L-D1)/V1 + L/V2, L/V2), so the global optimal solution should satisfy:

$(L-D2)/V2 < (L-D1)/V1$,
$(L-D1)/V2 + L/V1 < (L-D1)/V1 + L/V2$.

V1 = V2 in this situation, so the conditions are satisfied and Plan2 is better when D1 < D2. But D1 and D2 still involve the other side's information, and the utilization of such convention will increase the communicative overhead. So the convention can be transformed further with other knowledge about this situation, that is, D1+D2 = L/2, to clear the variable of the other side. Now we get D1 < L/4,

$D2 > 1/4$, and this is the convention mentioned above.

The meaningful emergence of convention in dynamic and open environments should be composed of the following steps:

- The emergent convention cannot be assigned in advance by the designer of system, and cannot be generated directly with simple actions, but must be the result of complex inference operation by some agents. Each agent is continuously making inference about the action strategy, and generates different strategies.
- The strategy generated in concrete situations cannot be used as convention, but should be generalized and abstracted to the form of convention.
- The strategy generated by specific agent will not be obeyed automatically by all agents, and must be propagated and selected among agent group. An agent can send its own strategy to relative agents, then the relative agent evaluates the influence of the strategy to it. If the strategy is beneficial to it, it will accept it as convention, otherwise it will reject it.
- The emergence of convention in the group scale is the acceptance of beneficial strategy by most of group members.

The delivery of convention to other agents can be accomplished by the means of broadcast, but a better way is to send it when interaction if the other side does not know about it. Since the convention is a kind of plan in fact, the other agent can evaluate it and decide whether to accept. The broadcast is not desirable in open system and large scale system. In open system, new agents may join continually, which do not know the conventions already established in the system. The broadcast in large scale system needs a large amount of communicative resource, deteriorating the communication seriously.

Characteristics of Agent Behavior during Emergence of conventions

To emerge out conventions, we assume that agents should own such characteristics: 1). Able to get those environmental features, such as their positions and their moving paths; 2). Able to plan and communicate to generate joint plan when interaction; 3). The goal of agent is to increase its utility in the long term running; 4). Able to compute the impact of convention to its average utility, and choose the beneficial conventions.

Agent is able to plan to accomplish a goal G in accordance with the current environment. Plan P = state(A,t), the functions of one or more agents' states with t. The plan formed by two or more agents' state function is joint plan. When an agent generates joint plan to G with other agents, it should generate an initial version of joint plan, then exchanges and negotiate with the other agent. When generating joint plan, an agent must make assumptions about the plans of the others, so the joint plan is based on these assumptions. Since the actions of others in the joint plan is assumed, the plan must be exchanged for check, adjustment and coordination, then be revised. The loop of exchanging and negotiating may be repeated many times to get the final coordinated plan, and cost large amount of computational resource. Once a plan is generated, the participant agents can generalize it, omit some factors specific to the current interactive situation, and make it a guide to the actions in similar situations in future. A convention is thus constructed.

The behavior of agents in the emergence process is as follows: To plan in the daily concrete situations; To generalize and expand the plan to a kind of rule for both sides of interaction; To send this plan to certain agents as convention with its revenue; If received a proposed convention, to evaluate it and accept it if beneficial; In the following interactions, use this convention if the other side abides it ; If the convention is spread out to the whole group, the confirmation of convention observance in the interaction also can be saved, so as to increase the efficiency.

The plans as the origination of convention are not simple selection among actions, and the abstraction from plan to convention needs strong intelligence. This shows the first requirement for emergence, that is, the construction of convention cannot be simple to list out some strategies for agent to select, as that in (Walker & Wooldridge 1995).

The agents in our emergence mechanism are required to own some behavior abilities, so this mechanism cannot be used in those multiagent systems that is composed of simple agents without planning ability. After all, this mechanism is designed for those complex systems in complex and dynamic environments.

One example of the possible complex behavior conventions which can emerge from this mechanism is how to allocate the social roles in certain situations among a group of agents that own different abilities and knowledge. In computational market, different agents own various resources and abilities. When allocating a new task among a group of agents, the agents should submit their problem-solving cost, then the contracted agents are chosen by an arbitrator or a market. This arbitration and market transaction require additional charge to the problem solving. In order to avoid such charge in procedural group problem solving, it is necessary for the group to allocate the roles not through market, but through direct group action. This is just how a company group is formed in the human economic activities. When the group generates its first role allocation under a certain task requirement, it can generalize this situation and the allocation to a task-role prescription. When the group meet a similar task, it can use this prescription to guide those agents evolved in the task according to the respective roles of agents. This effectiveness of this prescription is judged by those evolved agents. If it is beneficial to most agents, it can be accepted gradually by them.

Propagation and Execution of Conventions

The agent abiding a convention can send the convention to other agent when interaction. The agent receiving the convention makes utility analysis and will accept it if it is beneficial, otherwise deny it.

Turn back to the above example. If the generalized plan is: no matter which position the agent is in, X (any agent) must move back before A2, such convention is beneficial only to A2, and hurts all other agents. Even if A2 generates such a convention and send it to others, others would not accept it. In the mentioned L/4 convention, every agent may stay at random position in the channel when it meets another one, and the distribution of position possibility is mean in [0, L/2], so the expected position is L/4. Each agent may be placed in favorable position or unfavorable one with the same opportunity, and the total effect is that it will not increase the time for an agent to pass the channel. In other side, the adoption of the convention will save inference and communication cost, and leads to better long term efficiency. So an agent will accept it after utility analysis.

The execution of convention is guiding the agents to act interactively. In the system with some conventions, the action of agents when interacting is as follows:

1) Check the library of conventions. If each has a useful convention (the convention's condition is satisfied by the current situation), called C1 and C2 respectively, and both conventions are compatible with the other, the agents should act along with the action sequence defined in the conventions.
2) If the conventions are not compatible, the agents will evaluate them according to the criteria for joint plan selection and select the more optimal one, supposing C1. The agent that did not accept C1 before this interaction should compute the average utility increment Delta(C1) by C1, and substitute C2 with C1 if Delta(C1) > Delta(C2).
3) If only one side of the interaction has a useful convention, the agent sends it to another side, and both act according to the convention. The agent receiving the convention computes the average utility increment Delta(C1), and accept it if Delta(C1) > 0.
4) If both have no useful convention, they make joint plan and generalize the plan to a new convention.

In phase 1, an agent distinguishes a partner of interaction. When two agents meet each other, they exchange their convention code and judge if they can comply a common or compatible convention. If this is true, they become partners in the interaction, and so eliminate the need for joint planning.

In phase 2 and phase 3, the conventions are disseminated in group. Through these steps, the more beneficial convention can be accepted by more and more agents, and eventually become the dominating rule in this group. Since it is possible that many different convents for a same situation exist in the group, the competition among them is an interesting subject for study, and deserve further research.

In phase 4, agents generate plans and convert it to a new convention. They can utilize various planning techniques available. Our emergence mechanism just uses the results of planning process, and provides a flexible frame for different planning implementation. By separating the planning level from the convention emergence, we can accomplish uniform emergence on different infrastructures.

Quantitative Model for Propagation of Conventions

To analyze the emergent process of conventions, we should study the propagating speed, the maximal range of spread and the stable degree for different conventions. The propagating speed represents the adaptive ability of the system to dynamic environments. If a new convention can be spread out to the whole system very quickly, the system can adapt to dynamic environments smoothly. In other side, if the establishment of new convention is slower than the variation rate of environment, the system has to construct new convention and propagate it continuously among the agents, and is hard to keep up with the variation of environment. The maximal range of spread shows the range suited for the convention.

A quantitative study for the propagation of two-sided convention in agent group is described here. To study the propagation, we build the following model:

Assumption. There are N agents in the studied group. In some situation, both side of the interaction generate a joint plan P with cost C. The two agents are A1 and A2 respectively. P will bring revenue R1 to A1, and R2 to A2 (R1 > R2). After the plan P is converted to convention, the possibility for some agent, call it a, to stay at the position of A1 is P(a), and the possibility at A2 is 1-P(a). P(a) reflects the characters of the agent a in the environment and is determined by the agent's abilities and running history.

We can get the average revenue for a to obey the convention:

$$R = P(a) \cdot R1 + (1-P(a)) \cdot R2 \qquad (1)$$

If R > -C, P is acceptable for a. That means:

$P(a) > -(C+R2) / (R1-R2)$ (2)

If $C+R2 \geq 0$, since $P(a) \geq 0$, formula (2) is always true, and the convention will be accepted by all agents.

If $C+R2 < 0$, the acceptance should be judged with the specific value of P(a).

Consider the whole system, and suppose that Q(x) is the ratio of those agents satisfying P(a) = x to the total agents number. Obviously, $Q(x) \geq 0$ and $\int_0^1 Q(x)dx = 1$, that is, all of the value for P(a) is in [0,1]. We can get the acceptance range for the convention with $\Gamma = \int_{-\frac{C+R2}{R1-R2}}^{1} Q(x)dx$. Call the set of those agents accepting the convention conventional subgroup. Γ is the ratio of those agents accepting this convention in the whole group.

Now compute the propagation speed of the convention. Suppose the interaction which situation is defined in the convention occurs with a frequency of fc per unit time, and the frequency for all kinds of interaction is f (f > fc). The propagation can be accomplished by: 1) propagate only at the situation when the convention is in use. 2) propagate at any interaction.

Suppose that the possibility for interaction between any two agents is equal, that is, there is no locality in the interaction like (Kittock 1994).

If a convention is propagated in one interaction, both sides of the interaction must want to accept it, and one of them has formed this convention while the other still does not know about it. Supposing, at time t, the ratio of agents number having accepted the convention to all agents is $\rho(t)$, the possibility for such kind of interaction to occur is $P = \rho(\Gamma - \rho)$, and the ratio at the next time will be: $\rho + P \cdot fc / N$. We get the following differential equation:

$$\begin{cases} \dfrac{d\rho}{dt} = \dfrac{P \cdot f_c}{N} = \dfrac{\rho \cdot (\Gamma - \rho) \cdot f_c}{N} \\ \rho(0) = \Delta \end{cases} \quad (3)$$

Let k = fc / N, then get:

$$\rho(t) = \frac{1}{\frac{1}{\Gamma}(1 - e^{-\Gamma \cdot k \cdot t}) + \frac{1}{\Delta} \cdot e^{-\Gamma \cdot k \cdot t}} \quad (4)$$

In formula (4), $\rho(0) = \Delta$ and $\rho(\infty) = \Gamma$. This shows that after infinite long time the convention propagates to the whole conventional subgroup. Since ρ varies actually with discrete intervals, the most early time t for agent to expand to whole conventional subgroup must be:

$$\rho(t) \geq 1 / (1/\Gamma - 1/N),$$

that is: $(\frac{1}{\Delta} - \frac{1}{\Gamma}) \cdot e^{-\Gamma \cdot k \cdot t} \leq \frac{1}{N}$

we can get:

$$t \geq \frac{\ln \frac{N \cdot (\Gamma - \Delta)}{\Gamma \cdot \Delta}}{\Gamma \cdot k} = \frac{N \cdot \ln \frac{N \cdot (\Gamma - \Delta)}{\Gamma \cdot \Delta}}{\Gamma \cdot f_c} \quad (5)$$

The above results show that with larger Γ and larger interactive frequency fc, t will decrease, and the convention propagates more quickly. When the number of group N increases, the time for convention to spread will increase. The conclusion that Γ is in inverse ratio with t is not compatible with the intuition. Intuitively we can inference that with larger Γ, there will be more agents needed to be propagated to, and the time will be longer, but if we consider Γ influences the propagation interaction frequency, the synthesized result supports that propagation will be fast and t decrease.

Let m = f /N, the propagating speed for method 2 will be:

$$\rho(t) = \frac{1}{\frac{1}{\Gamma}(1 - e^{-\Gamma \cdot m \cdot t}) + \frac{1}{\Delta} \cdot e^{-\Gamma \cdot m \cdot t}} \quad (6)$$

Since f > fc, its propagating speed will be fast than method 1, but it requires more communication and more complex control mechanism for who to send, what to send and when to stop sending. The synthesized result will benefit method 1.

In the propagation of multi-sided conventions, the disseminating rate is determined also by the interacting rate and the characters of the participants in the interactions. The analysis method above is still effective.

Related Works and Discussions

Y.Shoham (Shoham & Tennenholtz 1992) discussed for a given social multiagent system and some focus states, how to define a set of social laws, which ensure that agents can generate plans transforming between those focus states. It is proved that the problem to find such a social law is NP-complete.

A.Walker (Walker & Wooldridge 1995) studied the efficiency of several mechanisms which use local information to get the global common strategy. That model includes only four possible conventions for agents, and agents must choose one among them according to the history and other agents' states. Only if most of agents choose the same convention, the convention can play its role fully in the interactions. The evolving mechanisms studied in Walker's model utilize the observed other agents' knowledge and local history. J.Kittock (Kittock 1994) studied the influence of the locality and authority of agent interaction to convention emergence. The convention means a common selection between two strategies there.

E.Durfee discussed the emergence of communicative protocols (Durfee, Gmytrasiewicz & Rosenschein 1994). The utility of communication is represented as the increased average utility with communicative actions, and every step in the communication is rationally based on the utility computation. So, based on utility analysis and computation, communicative interaction becomes agent's behavior emergent from the agent's rational selection, and the communication in specific situation gets specific structure, emerging into communication protocols in last. Communication protocols are actually conventions for both side of communication. This work shows that the convention can emerge from the utility analysis in communication.

The above works do not involve how to form new conventions for new situations in dynamic and open environments, and their convention concepts are relatively simple. The influence of knowledge propagation among agents to the convention emergence has been mentioned (Walker & Wooldridge 1995), but the propagated knowledge is just historical information. A.Walker's evolving mechanism includes a strategy with which an agent may suggest convention proposal to others, but the convention is simple and the knowledge utilization is not based on the utility analysis. E.Durfee's work proposed the utility analysis, but not mentioned the formation and propagation of conventions.

This paper establishes the convention emergence on the interactive planning of agents, making conventions generated naturally from the daily actions of agents, and able to process the plan-level complexity . Such conventions can adapt to the requirements to complex interactions by new situations in dynamic and open environments. The convention formation is based on the utility analysis of agents, ensuring the autonomous decision-making during the convention emergence. This paper also proposes a quantitative model for convention propagation, facilitating the study for convention valid range and spreading rate. The proposed mechanism provides a comprehensive frame, in which different agents can evolve into global coordination and rationality despite their discrepancy in the infrastructures.

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