Characterizing Multiplex Social Dynamics with Autonomy Oriented Computing

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Abstract

The study of social dynamics and social networks is the key to reveal the mystery of how local human interactions might lead to diversified global social patterns. Traditional work on these fields generally neglects a key character of social interaction - the multiplexity effect or the fact that people interact through different social context with different purpose and the potential coupled result. To study this problem, we select, inspired by existing work, two specific social interaction contexts: (1) cultural interaction and (2) decentralized social search. Extensive work has been done to characterize dynamics in both of them. However, the existing system level, centralized computational and mathematic models cannot characterize the fundamental social mechanism that forms the real world pattern (i.e. the persistence of cultural diversity, the efficient navigability of social network) because they neglect two important characters of social entities: the local autonomous behavior (i.e. the independent decision making ability under different situation) and the interaction incentive. To characterize the multiplex effect and those limitations, we propose a computational framework based on the bottom-up, autonomy-oriented computing (AOC) paradigm. Under the framework, a baseline model including a simple multiplex coupling mechanism is implemented. The simulation-based experiments demonstrate that the local autonomous coupled behavior could generate great influence on the global performance such as the resource utilization efficiency.

1 Introduction

The problem of linking the gap between local interaction among social entities (individuals, groups, organizations, etc) and the global society level patterns lays in the center of sociology [7] as well as social behavior data mining and modeling [12]. Social dynamics [4] and social network analysis [27] [30] are two research fields focusing on this problem. The former models the dynamic change of individuals' status like binary opinion and the resulting group dynamics such as rumor spreading [4]. The latter analyzes the static or dynamic characters of social tie (e.g. local connectivity) and the global patterns of the social network such as small world and scale-free structure [3].

1.1 The Multiplex Social Dynamics

Traditional work that modeling social dynamics and social networks generally neglects [30] one of the key characters of social interaction - the multiplexity effect. Multiplex means a social tie could serve as the channel to support social interaction with different roles and purposes [9][23] at the same time. And the cumulated result within one social interaction context will generate influence on the other. Therefore we believe that the work modeling the local global problem that does not take the multiplex effect into account may fail to reveal the true picture of social interaction.

To be concrete, we focus our study of multiplex effect on two specific social interaction contexts: (1) *cultural dynamics* and (2) *decentralized social search*. Here, culture refers to things (opinion, behavior, etc) that people could influence on one another [2]. Culture dynamics means people with similar features tend to cluster together with time passing by. On the other hand, decentralized social search means people search and share social resources with each other, i.e. valued goods (wealth, information, expertise, etc) that is embedded in the personal network accessible through social tie [14].

We choose these two social interaction contexts for two reasons: (1) *rationality* because the relationship of them has been discussed in sociological literatures [21] [16][22][24] and (2) *comparability* because a great number of modeling work has devoted to study each dynamic process so that we may compare our result with them. To name a few, the Axelrod model [2] and the extensions [5][29] characterize the persistence of cultural diversities with the local interaction of entities under different situations. Kleinberg [10][11] proposes a mathematic model to explain the small world phenomenon [28] and more importantly the fact that people can find the short route in the social network based only on local view. Following work [15] observe the pattern predicted by an extension of the model from the real world data.

1.2 Challenges

Although the above mentioned work characterizes the local global problem computationally or mathematically, they do not consider the multiplex character of social dynamics. Besides, a key limitation of these work is neglecting two most important characters of social entity: the local autonomous behavior (i.e. how entity behave differently under different situations) and the interaction incentive (i.e. why certain interaction take place).

Specifically, in the agent-based model [2] as well as the extensions [5][29]. Every agent is *homogeneous* in their behaviors during cultural interaction, such as randomly partner selection. In other words, the agent is not *autonomous* or *intelligence*. Because of this, the entire system can be implemented by only one scheduler agent. This centralized modeling perspective limits these models in characterizing and explaining the richness of real-world local social interactions.

On the other hand, although the Kleinberg models [10][11][15] characterize the social search behavior in a distributed and localized manner, their models cannot answer the further questions like why social networks can self-organize themselves to such a form that efficient local search can be supported [12]. This is because (1) the local autonomous behavior in search is not accounted and (2) the *open*, *dynamic* characters of social networks are neglected.

1.3 Our Considerations

In this work, we consider human society as an *open*, *dynamic* complex system. Here, the openness means both endogenous and exogenous perturbations can happen, such as the *cultural drift* discussed in [2][5]. The dynamic property refers to the constant creation and dissolution of social relationships. Under this perspective, social dynamic processes such as cultural dynamics and decentralized social search happen as the result of the localized autonomous interaction among individuals.

To achieve this purpose, we propose a computational framework based on the bottom up autonomy-oriented computing (AOC) paradigm [17]. Based on the proposed AOC framework (we will refer to AOC-MSD framework below), the local autonomous behavior and interaction incentive of social entities can be explicitly defined. Besides, the openness and dynamic aspects of human society can also be modeled.

In this paper, we report the current research progress on building the AOC-MSD framework. A baseline model including a simple multiplex coupling mechanism is implemented. The simulation-based experiments demonstrate that, even under this simple mechanism, the local autonomous coupling behavior could generate great influence on the global performance such as the resource utilization efficiency.

The rest of the paper is organized as follows. In section 2, we summarize several related work on social dynamics and social networks modeling. The detailed problem statement is given in section 3. The autonomy-oriented computing framework is proposed in section 4 with the baseline model implemented in section 5. The preliminary experimental results are presented in section 6. In section 7 we draw the conclusion and point out the future directions.

2 Related Work

In this section, we first justify the interrelationship of cultural dynamics and social resource sharing dynamics by surveying sociological literatures. Then we highlight modeling work on each types of social dynamics.

2.1 Relationship of the Two Dynamic Processes

To infer the relationship between the dual dynamic processes, two questions can be naturally raised: (1) does the interpersonal similarity (i.e. sharing more cultural attributes) affect the resource mobilization and utilization? (2) does the social support process inversely affect the interpersonal cultural interaction?

The answer to the first question is definitely yes. Picklert et al. [24] demonstrates that similarities among people can foster mutual support. Lizardo [21] points out that cultural taste helps constructing social relations, establishing networks of trusting relations and facilitating resource mobilization. Lin also points out that "greater similarity of shared resources may be indicated by the greater homophily among members" and vise versa [16]. Therefore, the local cultural interaction could generate effect on resource sharing behaviors.

The answer to the second question is, however, still elusive. McPherson et al. [22] calls for study the effect of multiplex social ties on the process of homophily interaction. However, neither empirical analysis nor theoretical modeling has been done to address this question. Therefore, it is an open question and we intend to address it in this research project.

2.2 Cultural Dynamics Modeling

The work on cultural dynamics mainly focuses on the following research question: why does the heterogeneity of cultural tastes among a group of people persist under the mutual reinforcement of homophily principle [22] and social influence?

The purpose of the Axelrod [2] model is to address this question. However, it is a centralized and system-level

model in the sense that the entities in the model are *not autonomous*. All the behaviors are randomly based probability rules and they are *homogeneous* for all individuals. For example, the ego chooses the interaction partner uniformly randomly from its neighbors. Although under this assumption the core mechanism of homophily interaction and social influence can be emphasized, it is far from realistic social interaction scenarios. Therefore, other social mechanisms and external factors truly exists in people's local cultural interactions cannot be accounted.

The network co-evolution model [5] mentioned above is also centralized and top-down in this sense. For example, in the random rewiring rule proposed in [5] an individual randomly chooses another one in the entire population and adds a new link with him. Although in [29], the authors consider the heterogeneity of individual's contact accessibility, other aspects are similar to the Axelrod model thus no explicit autonomous behavior exists for an individual. This centralized modeling feature also hold by other extensions and variations of the Axelrod model such as [13][8]. A good survey of this line of models can be referred to [4].

2.3 Decentralized Social Search

Why does social networks, without any centralized control, could self-organize themselves to such a state that search strategy based only on local view can be adopted to efficiently locate faraway target (e.g. people far across the country [28], resource arbitrarily distributed [6])?

Kleinberg [10] proposes a mathematic model to study this problem. A model parameter r is used to tune the probability that any two individuals u and v on the two dimensional lattice with distance d is connected at long range. The result shows that when r equals 2, a decentralized search algorithm can make best use of the geographic information in the long range connections to do efficient search.

A following work by Liben-Nowell et al. [15] empirically observes the geographic information and friendship links within a dataset extracted from LiveJournal - an online social network site. They generalize the Kleinberg model by taking the non-uniform distribution of the population density into consideration. The data analysis result shows the the social network in LiveJournal indeed shows the navigability predicted by their model.

Although the above mathematical model and related simulation characterizes the efficient navigability of social network, they still have not solved the mystery raised ahead because we can still ask the question why people form friendship in such a form that efficient navigability can be achieved [12]? Therefore, the underlying factors that generate the navigability of social network is still a *fascinating open question* [12].

Recently, several work adopting the autonomy-oriented computing method [17] has deepened our understanding on this question. Specifically, Zhang and Liu [32] proposes a representative model of dynamic evolving social network from the perspective of service transaction. Following this view, Qiu and Liu [25] studies the issue of efficient decentralized search in the trust network. Based on the proposed trust relationship evolving mechanism, they find the network could self-organize itself to scale-free connection pattern as well as achieving efficient target finding.

In this work, we will follow the AOC method to formulate the social resource search and sharing dynamics. However, our work focuses on the multiplexity effect of social dynamics stated in detail below.

3 Research Problem Statement

As mentioned above, the purpose of this study is to examine the *multiplexity effect* of social dynamics. In current stage, we focus our attention on two specific social interaction contexts, namely, cultural dynamics and resource sharing dynamics. We need to answer the following three categories of questions so that the research problem can be specified.

1. To formalize the cultural dynamics, we modify the framework proposed in [2] by modeling the autonomous behavior so that more realistic interaction scenario can be captured. Specifically, the following questions should be addressed:
    - How to design the autonomous behavior rules in the cultural interaction i.e. partner selection? What kind of incentive is suitable to model the motivation of cultural interaction? How to formally define it? How do individuals update their incentives?
2. In order to characterize the social resource sharing process from the autonomous perspective, we need to formally answer:
    - How to model social resource? What is the resource sharing dynamics? How do individuals generate resource needs and enquiry messages? How does an enquiry information propagate in the social network? How do individuals make referral if they do not have the resources? How do they offer help if they have access to them?
3. Most importantly, to specify the term *multiplexity effect* we need to answer:
    - How to design a mechanism that couple the two types of social dynamics at the local interaction level?

- What are the measurements to characterize the global performance of cultural dynamics and resource sharing dynamics?
- How does the local coupling mechanism affect the global performance of each dynamic process?

To build the AOC-MSD framework to study these questions, we summarize them into the following tasks:

1. Modeling the two types of social dynamics which includes two tasks: (1) construct the individual's social interaction profile, i.e. individual attributes, autonomous behavior rules; (2) design the mechanism reflecting the coupling relationship of the two types of behaviors.
2. Measuring the evolution of cultural regions and the resulting cultural diversity. Examining the resource utilization efficiency with predefined measurement. Currently we use: (1) the average resources accessability; (2) the ratio of satisfied enquiry to the total number of enquiry messages.
3. Testing the way different cultural diversity affect the resource utilization efficiency. Inversely, examining the way different resource utilization affect the evolving of culture diversity.

4 The AOC-based Framework

4.1 Basic Ideas

As is mentioned above, we intend to characterize the *multiplex social dynamics problem* based on the methodology of AOC [18][19][17] so that the *distributed*, *autonomous* characters of the local social interaction and the *open*, *dynamic* features of the global social patterns can be modeled.

One of the key purposes of AOC is modeling complex system [17] from the bottom-up perspective. The building-blocks of the complex systems or entities autonomously interact with each other and the environment through the existing or dynamically changing coupling relationship. Through the locally incorporated self-organization computability, certain global patterns will emerge (e.g. web surfing regularities [20], HIV Immune patterns [31]).

In this AOC-based framework, we consider the human society as a complex system composed by social entities interacting with each other in cultural and resource sharing dynamic processes. In Section 4.2 we introduce the profile of social entities. The local autonomous behavior of entities is presented in Section 4.3. To characterize the multiplexity effect, the local behavior coupling is presented in Section 4.4.

4.2 Social Entity Profile

4.2.1 Basic Ideas

Active entities are the key elements of an AOC system because they represent the building-blocks of the complex system under consideration. In the AOC-MSD framework, an entity represents an individual involved in the cultural interactions and/or resource sharing interaction. Below we introduce the profile of an social entity.

Definition 1 *A social **entity** e represents an individual involved in social interactions, i.e. communicating mutual interests, sharing social resource. It can be formally defined as a tuple, i.e. $e_i =< id, attribute, rules >$, where id denotes the identifier, $attribute = \{attr_{cul}, attr_{res}\}$ represents the attribute of e related to culture and resource sharing dynamics respectively. $rules = \{rule_{cul}, rule_{res}\}$ denotes the behavior rules related to the two dynamic processes.*

The entity profile defined above demonstrates the idea that any entity can involve in both cultural and resource sharing dynamics. Therefore, they have states related to each of them, represented by $attr_{cul}$ and $attr_{res}$. Below, we introduces them respectively.

4.2.2 Cultural Interaction Attributes

Culture at the individual level can be understanded as the things that people can influence one another [2] such as movie taste. In the current framework, we follow the definition of culture proposed in [2] in which each entity hold a cultural vector, denoting the current states on each different cultural features. The cultural trait represents the state value of the entity on one feature. Formally, it could be defined as:

Definition 2 *The **Culture vector** of entity e, i.e. $e.V_{culture} = [\sigma_1, \sigma_2, \ldots, \sigma_{F_c}]$ has F_c number of **cultural features**. Each feature may stand for cultural related individual characters such as musical choice, clothing preference, reading interests, etc. Each feature has q possible **trait** values i.e. $\sigma_i \in \{0, q-1\}$ to represent the difference of individuals on that feature.*

Therefore, in the current framework, we have $attr_{cul} = V_{culture}$. Based on the above definition, we could further introduce the *cultural similarity* [2][5] to characterize how *similar* two entities are.

Definition 3 *The **culture similarity** $sim(i, j)$ denotes the overlap of the cultural feature value of two entities e_i and e_j, i.e.*

$$sim(i,j) = \frac{1}{F_c} \cdot \sum_{f=1}^{F_c} \delta(\sigma_{if}, \sigma_{jf}) \quad (1)$$

4.2.3 Resource Sharing Interaction Attributes

Social resource means valued goods (wealth, information, expertise) that is embedded in the personal network and accessible through direct neighbors or further referrals [14].

Similar to the $attr_{cul}$ entities have resource sharing related state in the AOC-MSD framework. It denotes whether or not an entity holds or can access certain social resource. Formally, it could be defined as:

Definition 4 ***Social resource*** *embedded in the social network is denoted as r_i, i.e. the ith resource type. The resource accessibility of an entity e is represented as* ***resource memory****, $e.M_{resource} = [r_1, \ldots, r_{R_c}], r_i \in \{0, 1\}$. R_c is a parameter representing the number of possible resources in the artificial society.*

Therefore, in the current framework, we have $attr_{res} = M_{resource}$. The state variables of an entity e, i.e. $e.V_{culture}$ and $e.M_{resource}$ are dynamically changed by the local autonomous behaviors introduced below.

4.3 Local Autonomous Behaviors

4.3.1 Basic Ideas

In the AOC approach, the autonomy is reflected by the different local behavior rules triggered internally or externally by certain conditions [17]. In the AOC-MSD framework, the local behavior rules naturally related to the two social interaction contexts.

The list of the behaviors identified in culture and resource sharing dynamics are listed in Table 1. In this table, two columns correspond to two social interaction contexts, each of which contains three categories of behaviors to be specified below.

Table 1: Local behavior in two social interactions.

Cultural interaction	Resource sharing dynamics
initiating	resource enquiry
parter selection	information handling
homophily conform	enquiry checking

4.3.2 Cultural Interaction Behavior Rules

The cultural interaction related behavior rules are summarized in Table 2.

The first column denotes four types of cultural interaction initiating strategies. The first two types are intuitive. The *affinity* means each entity will decide whether or not to initiate an interaction according to its past cultural interaction results - or accumulated utility. It serves as the interaction incentive. In this framework, we name this utility as *affinity*. The rationality and definition will be given in section 4.4. R^{TH}_{happen} means each entity will decide whether to initiate a cultural interaction only after the average local sensed cultural similarity in its neighbors exceeds a threshold value.

Table 2: Local behavior strategies in cultural interaction.

Initiating	Partner selection	Homophily
always R^{AW}_{happen}	random R^{RD}_{select}	objective R^{obj}_{homo}
random R^{RD}_{happen}	affinity R^{AF}_{select}	subjective R^{sbj}_{homo}
affinity R^{AF}_{happen}	multiplexity R^{MP}_{select}	
threshold R^{TH}_{happen}		

The second column corresponds to the partner selection behavior. Three strategies are included. The random and affinity based rules are similar to the previous ones in first column. The multiplex strategy R^{MP}_{sel} means an entity e_i chooses an interaction partner not only depend on the current affinity but also affected by the result of the other types of social interaction.

The third column denotes how two entities perform the homophily interaction. $R^{obj}_{homophily}$ is used widely in the system-level model [2][5]. In this strategy, the entire cultural vector is used to calculate the cultural similarity. Compared with $R^{obj}_{homophily}$, the strategy $R^{sbj}_{homophily}$ means the entity only sense parts of its neighbor's cultural features. Besides, in this subjective perceive [26] rule, we could further modeling the biased perception as well as erroneous/fake perception.

4.3.3 Resource Sharing Behavior Rules

The detailed resource sharing related behaviors are summarized in Table 3.

Table 3: Local behaviors in resource sharing dynamics.

Resource enquiry	Information handling	Enquiry checking
happen	reply	utility updating
generating	referral	
parter selection		

The meaning of the behaviors in the first column is similar to the cultural behaviors. In the second column, R^{res}_{reply} denotes the feedback strategies if the entity holds the resource being requested. R^{res}_{trans} means that if the entity does not hold the enquired resource, whether and how will

it transmit the enquiry. Finally, $R^{res}_{trust\_upd}$ denotes how the entity update the utility. The notion of *trust* is presented below.

4.4 Multiplex Coupling Relationship

4.4.1 Basic Ideas

In the AOC approach, *coupling* denotes certain constraint relationship among the entities and/or with the environment [17]. In this sense, the multiplexity character of social tie can be considered as, in essence, a *coupling relationship* among entities' local autonomous behavior in different dynamic processes. In this section, we present a *social tie strength* based multiplex coupling mechanism.

The basic assumption under this multiplex mechanism is: the strength of social tie is affected by the contact time and frequency [7] in different social interaction contexts, i.e. cultural interaction and resource sharing interaction. Inversely, the tie strength will further affect the interaction probabilities.

4.4.2 The Nature of Social Tie

In the AOC-MSD framework, the nature of social tie is the *cumulate results* of multiple social interactions. In the cultural dynamics, the like minded persons tend to cluster together and become more similar. The process naturally changes the *affinity relationship* among community members. Here, *affinity* means "ideas,ideals and causes shared by a tight community" [1].

On the other hand, the resource sharing dynamics demonstrates *why* and *how* people provide mutual support or different kinds of services to each other. Interpersonal *trust* can be taken as the natural production of this process. Here, *trust* reflects the belief or confident of ego that the relationship partner will behave as expected [9], e.g. provides service (e.g. resource sharing or referral) as needed [25].

Formally, the idea can be presented as following:

Definition 5 *The **affinity** of entity e_i to e_j, i.e. $e_i.affinity(e_j,t)$ denote how much rewards e_i has received from the past cultural interaction with the neighbor e_j. It can be calculated as:*

$$e_i.affinity(e_j,t) = \frac{1}{1+e^{-suc_{ij}(t)}} \tag{2}$$

where $suc_{ij}(t)$ is the times of successful cultural interaction between e_i and e_j. Here successful *means e_i is successfully influenced by e_j at certain time t, i.e. change one of its cultural feature value.*

Definition 6 *The **trust** of entity e_i to e_j, i.e. $e_i.trust(e_j,t)$ denote the accumulated reward entity e_i has gained from past resource sharing with e_j, i.e.*

$$e_i.trust(e_j,t) = \frac{1}{1+e^{-sat_{ij}(t)}} \tag{3}$$

where $sat_{ij}(t)$ is the satisfied enquiry times entity e_i get from entity e_j so far.

Definition 7 *The **tie strength** $e_i.tieStrength(e_j,t)$ perceived by e_i on e_j is determined by both the affinity accumulated in the cultural interaction as well as the trust formed in the past resource sharing dynamics, i.e.*

$$e_i.tieStrength(e_j,t) = \alpha \cdot e_i.affinity(e_j,t) + (1-\alpha)\cdot e_i.trust(e_j,t) \tag{4}$$

where $\alpha \in [0,1]$ is a coefficient to adjust the weight of cultural interaction as well as the resource sharing interaction.

After defining the multiplex social tie, we may adopt it in the local autonomous behavior of entities in either of the social dynamic processes. Currently, the baseline model introduced below does not implement this mechanism, we will explore it in the future work.

Finally, the overview of the framework is illustrated in Figure 1.

5 Baseline Model

In this section, we introduce a baseline model implemented under the AOC-MSD framework . The purpose is to take the AOC-by-Prototyping approach [18][19] to incrementally address the proposed research question.

5.1 Cultural Dynamics Module

The model mechanism of cultural dynamics is demonstrated in Table 4. In the implementation, each social entity initiates the cultural interaction with one of its neighbors uniformly randomly chosen. The probability of homophily conform is proportional to the cultural similarity (definition3).

We have not included any autonomy mechanism in the cultural module in the baseline implementation such as affinity based initiating and partner selection rule. We intend to keep the model as simple as possible so that we may add one autonomous feature at a time and test the resulting effect.

5.2 Resource Sharing Dynamics Module

The model mechanism of resource sharing dynamics is shown in Table 5. The detailed meaning of the implemented behavior rules can be referred to section 4.

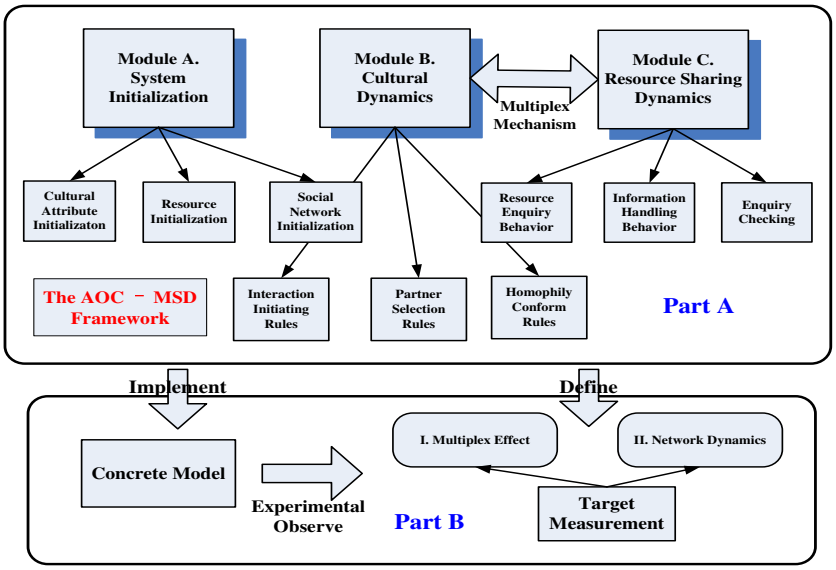


Figure 1: The AOC-MSD framework; In order to design a concrete model, three modules should be implemented: (1) initialization module, (2) cultural dynamics module and (3) resource sharing module. The target measurements focus on two aspects: (1) the multiplex effect and (2) the social network dynamics.

Table 4: Cultural dynamics module implementation. Detailed definition refers to section 4. Objective based rule means the probability of homophily interaction is based on the overlap of the cultural vectors.

Interaction Behavior	Implementation
Initiating behavior	Always initiate the culture interaction
Partner selection	Random choose a neighbor to interact
Homophily conform	Objective based rule

Table 5: Resource sharing dynamics module implementation. Detailed definition refers to section 4

Interaction Behavior	Implementation
Resource enquiry	R^{AW}_{happen}: happen at each time step R^{SG}_{gen}: single need each time step R^{RD}_{select}: random neighbor chosen
Information handling	R^{AW}_{reply}: always reply R^{SM}_{reply}: cultural similarity based R^{AW}_{trans}: always transmit
Enquiry checking	$R^{res}_{trust\_upd}$: not included

5.3 Multiplex Coupling Mechanism

In the baseline model, the tie strength coupling mechanism introduced in section 4.4 is not implemented. Instead, we design a simpler coupling mechanism including the following to aspects:

1. *Local profile based coupling* which reflects how the entities' state or local behavior in one dynamic process will affect those in the other type. More specifically, we make the assumption that entities *reply behavior* in social resource sharing interaction can take two possibilities: (1) always reply and (2) cultural similarity based reply. In the later one, the entities' cultural feature value will affect the resource sharing process. Experiment three below will address this.

2. *Global dynamics happen order* which reflects the happening order of the two dynamics. Two possibilities are: (1) *serial* coupled order and (2) *parallel* order. The former means the resource sharing dynamics happen after the convergence of cultural dynamics (i.e. no more local change of cultural feature value). The later means two dynamic processes will happen simultaneously. In the current baseline model, we implement the serial version.

5.4 System Initialization

To implement the baseline model, two further aspects should be mentioned:

- In the baseline model, we keep the initial social network structure as a two-dimensional lattice, like [2][5]. Besides, we do not incorporate any network dynamics, i.e. building and/or breaking social tie.

- Only one resource (i.e. R_a) is considered in the baseline model which is randomly distributed initially. We further introduce a model parameter eta to reflect the abundance of the resources (definition 4), i.e. initially there will be $N \cdot eta$ entities hold the resource.

6 Preliminary Experiments

In this section, corresponding to the above baseline model, we design three experiments that characterize: (1) cultural evolution (experiment one); (2) resource utilization (experiment two) and (3) multiplex coupling mechanism (experiment three). The model parameters used in these experiments is summarized in Table 6.

Table 6: The model parameters used in the following experiments

Symbol	Description
N	Number of social entities
F_c	Cultural feature number (definition 2)
q	Value range of one cultural feature (definition 2)
R_c	Number of social resource type (definition 4)
eta	The ratio of entities initially chosen as resource holder. It reflects the abundance of resources.
T_{lim}	Max enquiry message valid cycles (definition 4)

6.1 Evolution of Cultural Diversity

Motivation In this experiment, we intend to observe how cultural regions evolve. The target measurement is *cultural diversity* which follows the definition in [2][5]:

Definition 8 *The **culture diversity** $C_{div} = \langle S_{max} \rangle / N$ denotes the average size of the largest cultural region normalized by the the number of entity N.*

Here, one a *culture region* denotes a connected part of the social network within which all entities have the identical cultural features and out of which the values are entirely different.

Experimental Setting To observe the cultural region evolving, we use $N = 100, F_c = 3, q = 10$ for ease of visualization. To observe the clear phase transition phenomenon, we set $F_c = 3$ and change $q \in \{0, 1, \ldots, 40\}$, $N \in \{100, 400, 900\}$.

Observation and Discussion Figure 2 demonstrates a representative run of cultural dynamics in the baseline model which shows that after 1000 cycles, cultural regions with identical features (colors) emerge. This can be explained by the positive feedback mechanism designed in the model: the more similar two individuals the more likely they will interact thus will become more similar. Therefore, the overall tendency in the cultural dynamics is the convergence of cultural feature values.

Figure 3 illustrates the phase transition phenomenon observed in [2]. The result demonstrates that for fixed cultural feature value F_c, slightly change of trait range or q will lead to a dramatic change of the final cultural region. Besides, small q value will lead to the mono-cultural region while large q value will lead to the highly cultural diversity.

6.2 Resource Utilization Efficiency

Motivation In this experiment, we intend to observe the global performance of resource sharing dynamics. The target measurement is defined as follows:

Definition 9 *The **resource access ratio** of an entity at time t or $R^i_{acc}(t)$ is the number of resources entity e_i could access at time t proportion to the total number of resources in the artificial society. The **average resource access ratio** is the average of R^i_{acc} on all entities.*

Intuitively, the more resources accessible by all people in the social network, the more utilization efficiency of the society. Another intuitive aspect is related to how many enquiries are satisfied defined as:

Definition 10 *The **enquiry satisfied ratio** S_{eq} is the fraction of all satisfied enquiry messages to the total generated enquiry messages.*

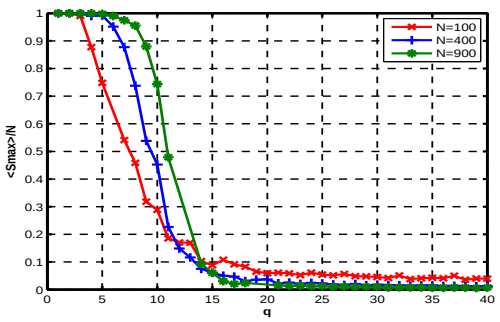
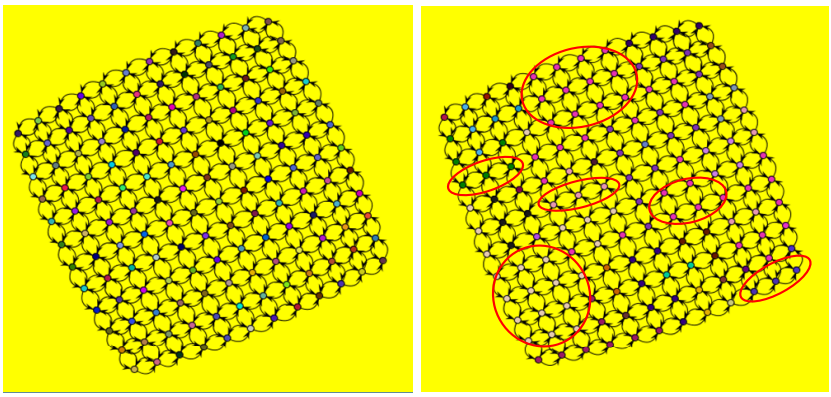


Figure 3: Phase transition of cultural diversity with the change of cultural trait value. With the decrease of q, the cultural diversity change from mono-state to diversity state in a sudden manner



(a) A possible initial state T= 0 - random color

(b) In the middle run T≈10^3 – color regions emerge

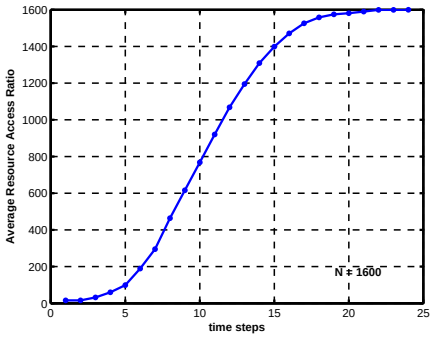
Figure 2: Cultural region evolving, with different colors denote different cultural vector value. The result shows that (a) initially at $T = 0$ nearly all entities are different with each other; (b) at $T = 1000$ steps multiple cultural regions emerge.

Experimental Setting To observe the resource access ratio, we use $N = 1600, R_c = 1, eta = 1\%$. To examine the enquiry satisfied ratio under different resource abundance, we use $N = 100, R_c = 1, eta \in \{0.01, 0.02, 0.04, 0.1, 0.2, \ldots, 0.9\}$. In both scenario $T_{lim} \sim Noraml(2, 5)$.

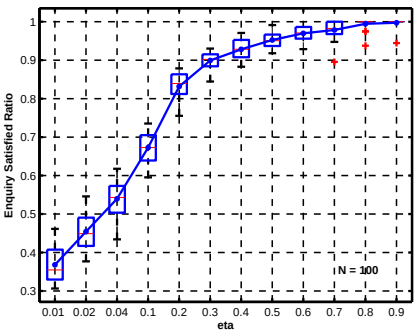
Observation and Discussion Figure 4(a) shows that all entities could access the resource R_a finally under the experimental setting. Besides, the convergence curve exhibits the sigmoid shape.

The first observation is not plausible in the sense that in reality, some entities may not be able to access the resource no matter how many enquiries are made through his local social circle. Besides, we conjecture that the sigmoid curve is due to a positive feedback in the baseline model setting. A model hypothesis is once an entity gets the accessability of the resource, it can further offer it to others. As a result, the more entities can access R_a the quicker the rest entities can access it. This observation leads us to further consider the **type** of resource to be modeled, i.e. the information or expertise resource is rather different from the material based resource.

The result in Figure 4(b) is trivial in the sense that the more resource abundance in the society, the easier an enquiry can be satisfied. However, an efficient resource utilization society should be, under certain model mechanism, less abundance resource can still satisfy most resource enquiries. We plan to address this issue in the future model implementations.



(a) average resource access ratio change with time steps

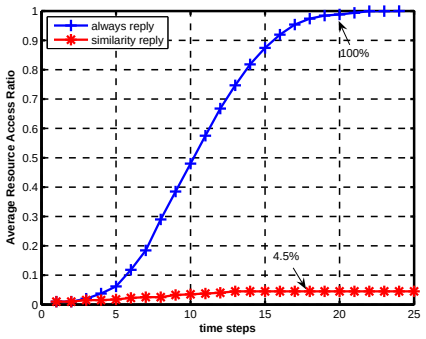


(b) enquiry satisfied ratio change with resource abundance parameter *eta*

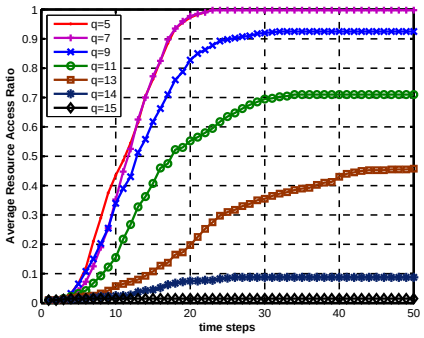
Figure 4: Resource utilization efficacy:(a)all entities could access the resource finally,(b)the more abundance of resource the more enquiry messages are satisfied

6.3 Multiplex Coupling Effect

Motivation In this experiment, we intend to test the multiplex coupled mechanism implemented in the baseline model.



(a) comparison the two local reply rules on average resource access ratio



(b) comparison the effect of different cultural diversity on average resource access ratio

Figure 5: The effect of cultural similarity based reply rule on resource utilization:(a)entities using the *always reply* rule could quickly access the resources while with *cultural similarity based reply* only 4.5% could access the resource,(b)with the increase of q, the order parameter control cultural diversity, the average resource access ratio decrease quickly.

Experimental Setting To examine the effect of local profile based coupling we use $N = 400, F_c = 1, q = 15, R_c = 1, eta = 1\%, T_{lim} \sim Normal(2, 5)$ in the first part of the experiment. To test the effect of cultural diversity on the resource sharing, we change $q \in \{5, 7, 9, 11, 13, 14, 15\}$ in the second part.

Observation and Discussion From Figure 5(a), we may observe the final average resource access ratio is inhibited under the cultural similarity based reply rule. We conjecture the reason for the inhibition can be explained as follows: (1) because of the serial dynamics happen order, the resource sharing dynamics will happen on cultural region that has already formed (see experiment one); (2) the resource is initially randomly distributed, therefore entities in one cultural region may not be able to access the resource located in the other regions because of the cultural boundary.

In order to validate the above explanation, we change the cultural trait range value q and observe the effect of cultural diversity on the average resource utilization. As we have observed in Figure 3, there is a phase transition in the maximal cultural region size by increasing the q value. Therefore, we may expect that, with the increase of q value, the effect of inhibition will also be increased. Figure 5(b) demonstrates this conjecture. More than 90% entities could access the resource in the society when q is smaller than 9. However, when q increases to 14 the proportion decreases to less than 10%.

7 Conclusion and Future Work

In this work, we propose an autonomy-oriented computing framework, the AOC-MSD framework, to study the multiplexity effect of social dynamics, namely the multiple channels of social interactions and the coupling results of the dynamics processes. Specifically, we formalize the local autonomous behaviors in cultural taste based social interaction and resource sharing based social interaction. In this framework, a social tie strength based coupling mechanism is proposed to characterize the interaction incentive and multiplex nature of social interaction.

A baseline model based on the AOC-MSD framework is implemented and three preliminary experiments have been done to characterize: (1) the cultural evolution, (2) the resource sharing efficiency and (3) the multiplexity effect. Experimental results show that the cultural similarity based reply rule can generate significant influence on the resource utilization efficiency. Specifically, the more cultural diversity exists in the society, the less possibility community members could access the resources in need.

Our future work will mainly focus on the following aspects: (1) refining the design of entity's resource profile and the resource initialization rule, (2) implementing the tie strength based multiplex mechanism and examining the coupling effect by conducting systematic experiments, (3) incorporating the network dynamics in the local autonomous behaviors to capture the creation and dissolution of social relationship and observe its effect on the evolving of cultural diversity and the resource utilization efficiency.

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