SETE: A Trans-Boundary Evolution Model of Service Ecosystem Based on Diversity Measurement

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Abstract. Trans-boundary and integration are important characteristics of the development of modern service industry. With the development of Internet technology, trans-boundary cooperation between domains constantly emerges, which drives the development of service ecosystem. Currently, there is a lack of an appropriate model for analyzing the impact of trans-boundary services on the entire service ecosystem. In this paper, we propose a service ecosystem trans-boundary evolution model (SETE). It analyzes the interactions between user needs and services, and focuses on the mechanism of trans-boundary services to promote the evolution of the service ecosystem. At the same time, we develop a diversity measurement algorithm for service ecosystems based on the theory of biodiversity in ecology. Based on these, a computational experimental system is established. It simulates the trans-boundary evolution mechanism of the service ecosystem and shows the characteristics of each stage of the service ecosystem evolution. At last, we verify the effectiveness of the SETE model through actual cases (the Alibaba Group). The results show that the SETE model can provide new ideas for the study of the trans-boundary evolution of the service ecosystem, and provide decision support for the development direction of the modern service industry.

Keywords: Diversity measurement · Service ecosystem · Trans-boundary service · Service evolution · Computational experiment

1 Introduction

The new social form of "Internet+" has promoted the trans-boundary and integration development between industries. Services are increasingly breaking traditional domain boundaries. Trans-boundary service provides users with innovative services through trans-domain cooperation, and creates value that a single-domain service cannot create [8]. Trans-boundary services and single-domain services work together to form a service ecosystem. As time goes by, dynamic cooperation between services has promoted the development of the service ecosystem

H. Gao et al. (Eds.): CollaborateCom 2020, LNICST 349, pp. 217–236, 2021.
https://doi.org/10.1007/978-3-030-67537-0_14

[20]. Therefore, studying how to characterize the trans-boundary evolution mechanism of the service ecosystem can help us better understand and manage it.

Before trans-boundary services were created, services came from different domains and service providers, and they did not have uniform development standards. Semantic conflicts make cross-domain collaboration between services very difficult. It not only limits the ability to create value of services, but also hinders the development of the service ecosystem. The trans-boundary service solves the problems. It establishes communication channels between domains, allows services between different domains to invoke each other, and provides users with a new user experience that cannot be provided by the single domain services. At the same time, the creation of trans-boundary services has a huge impact on the cooperation and competition relationships of services in the service ecosystem. The trans-boundary and integration of various domains has caused great changes in the diversity of the service ecosystem and promoted the evolution of the service ecosystem.

Research in this field is facing challenges. Firstly, the rapid changes in user needs and the rapid development of modern service industries make data volumes very large and difficult to obtain. Secondly, the complex and changeable service ecosystem makes it difficult to capture the regular pattern of the generation and evolution of trans-boundary services. In order to better understand the development of the service ecosystem, we attempt to build a model (SETE) based on the diversity measurement, and study the trans-boundary evolution mechanism of the service ecosystem. The main contributions of this article are as follows:

- Propose a model for trans-boundary evolution of the service ecosystem based on diversity measurement;
- The measurement algorithm designed to assess the diversity of service ecosystems;
- Prove the effectiveness of SETE through computational experiment and case study.

The rest of this article is organized as follows. Section 2 introduces the specific details of the SETE model. Section 3 introduces the mechanism of trans-boundary evolution. Section 4 describes the diversity measurement algorithm. Section 5 shows a computational experiment system and a case study to validate the model. Section 6 introduces the related work. Section 7 summarizes the research of this article.

2 Structure of SETE Model

As shown in Fig. 1, the service ecosystem can be viewed as a collection of services, the relationships between services, and other entities [7]. It is a system where multiple members create and share value together. It can be analyzed from four levels: service network level, value network level, domain level, and service ecosystem level. The service network level includes various web services, and the services form a network by invoking each other. The value network level contains value flow between services. The domain level contains resources such as specific value network their service providers, semantic rule bases, etc. The ecosystem level includes user needs and the environment. In order to better explain the trans-boundary evolution mechanism of the service ecosystem, we first define some basic concepts in the service ecosystem.

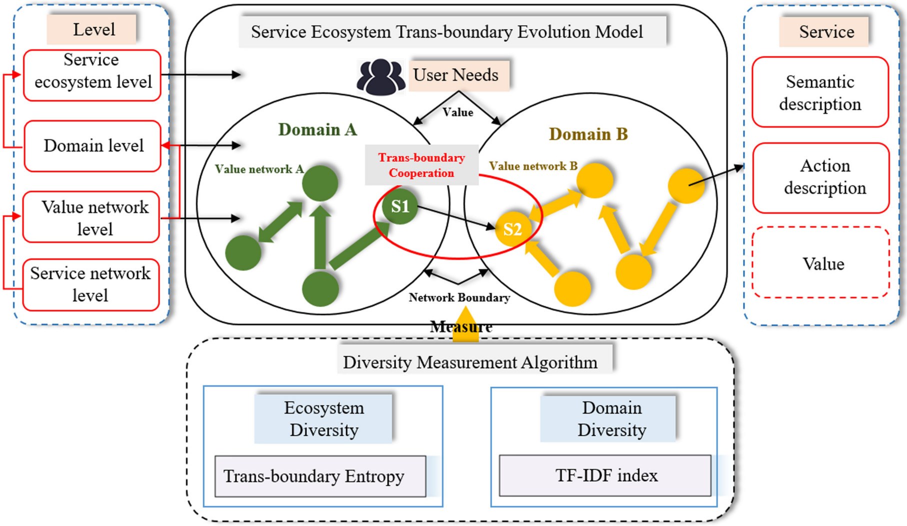

Fig. 1. Structure of the dynamic trans-boundary evolution model of the service ecosystem.

2.1 Service Network Level

Services provide users with solutions through cooperation, thus forming a network. The service network is the foundation of the domain structure and evolution of the service ecosystem and an important condition for trans-boundary evolution.

Theorem 1 (Service Network). *Facing diversified user demands, services need to invoke other services to complete the functions. The cooperative relationship between services influences each other and forms a service network. Services provide richer and more flexible solutions in the service network. The service network can be defined as a collection of cooperative relations in the domain*

$$SN = (V, E) \tag{1}$$

where V represents the set of points in SN and E is the set of edges in SN. And

$$V = \{S_1, S_2, \ldots, S_n\} \quad (2)$$

$$E = \{(S_i, S_j)\,|1 \leq i \leq n, 1 \leq j \leq n\} \quad (3)$$

where S represents a node in the service network, which is service. n represents the number of services in the service network.

Theorem 2 (Service). *The service ecosystem includes various types of participants. As the supplier of user demands, service plays an important role in the ecosystem. Under the service-oriented architecture (SOA), services can be classified into atomic service and composite service, which is composed of atomic services. Service can be defined by a two-tuple* $< Sem, Act >$. *Their definitions are shown below.*

- *Sem* describes the function of the service from the semantic level. We use a method based on IOPE to define service semantics [6]. Sem includes the collection of data resources required by the service to accomplish its functions (Inputs), the set of data resources generated by the service after completing its business functions (Outputs), prerequisites for using the service (Preconditions) and effects after using the service (Effects).
- *Act* describes the interaction of the service from the action level. The interaction includes the interaction between services and the interaction between a service and the environment. The set of interactions is $< DealOrder$, $Reproduction$, $Cooperation$, $Trans - boundary >$. *DealOrder* means that the service creates value by responding to invocations from users and other services. *Reproduction* refers to the expansion of atomic services. When the value of the service reaches a certain threshold, it will decide whether to develop atomic services to expand the business scope. *Cooperation* means that services will implement collaboration through mutual invocation, service integration, and other unforeseen ways. Trans-boundary refers to the innovation or improvement of services through the cross-domain integration of resources and capabilities.

2.2 Value Network Level

The value network is the foundation of the value flow in the service ecosystem. It's a necessary condition to promote the evolution and development of the service ecosystem. Service is the carrier of value. The flow of value is realized by mutual invocation between services.

Theorem 3 (Value Network). *Values are transferred between services through invocation, which forms a value network. There are a large number of cooperation relationships and value exchanges in the domain. The upstream service can call the downstream service, and the downstream service can feedback information for the upstream service. The node set and edge set of the value network VN are consistent with the corresponding service network SN.*

Theorem 4 (Service Value). *When users interact with services, both parties involve the interaction of information flow and cash flow. Users choose services that meet their needs, and service suppliers profit by providing services. Service value is the value generated when the service interacts with users. Service value describes the value that services create when interacting. The value of service s at time t can be defined*

$$V_s(t) = QoS_s(t) + price_s(t) * fre_s(t) - cost_s(t) \tag{4}$$

where $QoS_s(t)$ is the quality of the service, and it indicates whether the performance or availability of the service s can meet the demand of users. $QoS_s(t)$ will affect the number of users attracted by the service and the maximum number of times the service can be invoked per unit time. $QoS_s(t)$ will increase when the service is perfected, and decrease when the service is overloaded. $price_s(t)$ represents the price charged by the service each time it is invoked. $fre_s(t)$ represents the frequency the service is invoked, and the product of $price_s(t)$ and $fre_s(t)$ represents the revenue of service. $cost_s(t)$ is the cost of the service, including development costs, invocation costs, maintenance costs, etc. When the service needs to develop new function or improve current functions, development costs will be incurred. When the service needs to invoke other services, the service need the invocation costs. When a service is defective, service providers need to pay the cost of maintaining the service.

Theorem 5 (Network Boundary). *Different service networks are affected by issues such as semantic conflicts and interface mismatches, and cannot be invoked by each other. In other words, there is a network boundary between service networks. Suppose two value networks VN_A and VN_B. V_A and V_B denote their node set respectively. E_A and E_B denote their edge set respectively. Then there will be*

$$V_A \cap V_B = \emptyset \wedge E_A \cap E_B = \emptyset \tag{5}$$

Although domain boundaries make it impossible for services between domains to interact, domains can exchange information and value through service providers, shared user groups, etc.

2.3 Domain Level

The complex relationships between services and services, services and environment lead to the community structures in the ecosystem. Domain describes concepts and their relationships in a particular community structure and is used to analyze semantics and build rule bases.

Theorem 6 (Domain). *Different services belong to different community structures, which is the domain. Services in the same domain follow unified development standards, rules, and semantic libraries and meet specific user needs. In addition to the value network, the domain also includes service providers and the rule base. The formal formula to express the domain is*

$$Dom = (VN, RuleBase, Supplier) \tag{6}$$

RuleBase represents the semantic specification and rule base in the domain. *RuleBase* stores the mapping relationships between semantic concepts, which is used to detect and resolve semantic inconsistencies between web services. The mapping relationships can be manually added and modified. A mapping relationship can be formally represented by a five-tuple $(C1, C2, mapType, rule, cons)$, where $C1$ and $C2$ represent semantic concepts, mapType represents the type of semantic mapping relationship (such as equivalence, inclusion, irrelevance, etc.), *rule* represents the conversion rule between $C1$ and $C2$, and *cons* represents the constraint rule of this mapping.

Supplier represents the service suppliers that provide the services of the domain. Atomic web services have their own service suppliers, users obtain services through the service providers, and the profit pays the operation and service maintenance fee.

2.4 Ecosystem Level

Trans-boundary cooperation between domains meets users' growing and changing needs. Fusion and dynamic collaboration between services drive the service ecosystem to evolve.

Theorem 7 (Service Ecosystem). *Service ecosystem is a logical collection of network services [1]. In the service ecosystem, services obtain value by meeting the needs of users. In addition to various domains, the service ecosystem also includes users and the environment.*

$$SerEcosystem = (User, Environment, Dom_1, Dom_2, ..., Dom_m) \tag{7}$$

where $User$ represents the users who use the services in the service ecosystem, environment represents the basic environmental information of the entire ecosystem, and m represents the number of domains in the ecosystem.

Theorem 8 (Trans-boundary Service). *Trans-boundary service refers to the service that integrates services by service fusion or service matching in order to sole problems such as data inconsistencies and business inconsistencies. Trans-boundary service can interact with services in two domains by normal invocations. After the service integrated with other services, the service value becomes*

$$V_i' = V_i - \mathrm{cost}_{\mathrm{trans}} + \delta \tag{8}$$

where V_i' is the service value after trans-boundary, V_i is the service value before trans-boundary, $cost_{\mathrm{trans}}$is the value consumption generated by trans-boundary, and δ is the added value generated by trans-boundary. When $\delta \gg cost_{\mathrm{trans}}$, trans-boundary service can continue to develop.

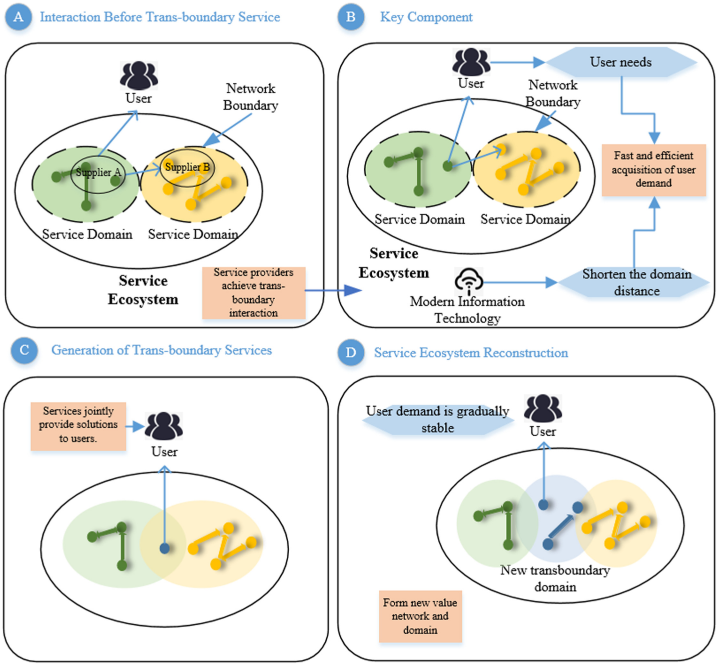

Fig. 2. Structure of trans-boundary evolution mechanism.

3 Mechanism of Trans-Boundary Evolution

Under the SETE model, we analyzed the differences between trans-boundary interactions before and after the trans-boundary service are generated and proposed the generation and mechanism of trans-boundary evolution. As shown in Fig. 2, part A shows the trans-boundary interaction before trans-boundary services are generated. Part B shows the key components. Part C and part D demonstrates the changes in the service ecosystem caused by trans-boundary services.

3.1 Interaction Before Trans-Boundary Service

Before the generation of trans-boundary service, services between domains cannot invoke each other. Interaction between domains needs to be completed by online web services and offline human behavior. The Trans-boundary interaction request before trans-boundary service generation can be defined as the following five-tuple:

$$TR_{pre} =< S_{id}, Dom, Supplier, des, output > \quad (9)$$

where S_{id} is the id of the service to request interaction, Dom is the domain of the service, des describes the function requested by the service, and $output$

describes the data resource collection generated by the service after completing its business. Because the *RuleBase* in different domains are not the same, the web service cannot find a service that matches *des* and *output* outside the *Dom*. Therefore, *Supplier* needs to solve the problem of inconsistent semantics and inconsistent interface parameters by offline communication and manual matching. The value cost of interaction before trans-boundary service is

$$Cost_{TR} = [price_s(t) + Cost_{labor}(t)] * fre_s(t); \quad (10)$$

where $Cost_{labor}(t)$ is the offline labor cost, and other parameters are similar to Eq. 4.

The time consumption of trans-boundary interaction also includes online time and offline time

$$Time_{TR} = [Time_{inv}(t) + Time_{labor}(t)] * fre_s(t) \quad (11)$$

where $Time_{inv}(t)$ is the time for a single invocation of the web service. This time is generally short. $Time_{labor}(t)$ is the time consumed by offline manual matching. Due to the high communication time cost and operation time cost, this time is long.

3.2 Key Components

The key components for the generation of trans-boundary services include the trans-boundary needs of users, modern information technologies, and the collection of services in the service ecosystem. User needs are rapidly changing and growing, which promotes cooperation between domains to propose innovative services. The modern information technologies have shortened the distance between users and services. Services can efficiently obtain user needs through methods such as big data analysis and cloud computing. The cross-domain interaction between services has provided a trans-boundary technical basis between domains. These help services to update and fuse to meet the evolving and diverse needs of users.

3.3 Generation of Trans-Boundary Service

Before the generation of trans-boundary service, the supply capacity of trans-boundary cooperation services is restricted by the rules of the two domains and the capabilities of offline entities. The increasing demand of users for high-quality and low-price services has promoted the integration of services and proposed innovative trans-boundary services. The service developers refactored the parameters between services in different domains and added the mapping rules of interface semantics to the *RuleBase* of the two domains. This solves the problem of inconsistencies in the service interface. And the services in different domains can invoke each other by S_{id} and *des*. Its supply capability is greatly improved.

After the generation of trans-boundary service, the cost of trans-boundary interaction is reduced to

$$Cost_{TR}' = price_s(t) * fre_s(t) \tag{12}$$

The time for trans-boundary interaction is also greatly shortened.

$$Time'_{TR} = Time_{inv}(t) * fre_s(t) \tag{13}$$

3.4 Service Ecosystem Reconstruction

Trans-boundary services have established a new domain system, and at the same time, it has made users break away from the original domains and enter the new. The new domain created by trans-boundary services attracts and stimulates user demand through its own service performance. After emerging domain occupies a certain share, the traditional domains are affected by new domains, resulting in changes in domain scale and value network structure. It leads to the complete disappearance of the traditional service ecosystem and the end of the trans-boundary evolution.

4 Diversity Measurement Algorithm

Because the boundaries of the service ecosystem are difficult to determine and the dynamic evolution mechanism is complex and changeable, how to measure the changes of the service ecosystem in the trans-boundary evolution is a difficult problem. We introduce the concept of biodiversity [12] in ecology into the service ecosystem, which is used to measure the stability of the service ecosystem and service capacity. Biodiversity believes that the stability of ecosystems is closely related to the number of species in the system and the size of interactions between species [5]. Studying the diversity of service ecosystems is important for maintaining their stability. The diversity measurement algorithm quantifies the characteristic indicators of the service ecosystem at each stage of trans-boundary evolution by measuring the trans-boundary entropy of the whole service ecosystem and the TF-IDF index of each domain.

4.1 Trans-Boundary Entropy

Entropy is a parameter representing the state of matter in thermodynamics, and it is a measure of the degree of chaos in the system. Shannon borrowed this idea from thermodynamics into information theory as a measure of the observation or measurement work involved in assessing the state of the system [13]. The higher the system's entropy value, the higher its overall complexity and diversity.

The evolving service ecosystem can be viewed as a network. IBM defines the state of the value network as the set of nodes participating in any given consumer interaction. Then, the information entropy is used to calculate the complexity of the value network [2]. We define the interaction set as the set of trans-boundary

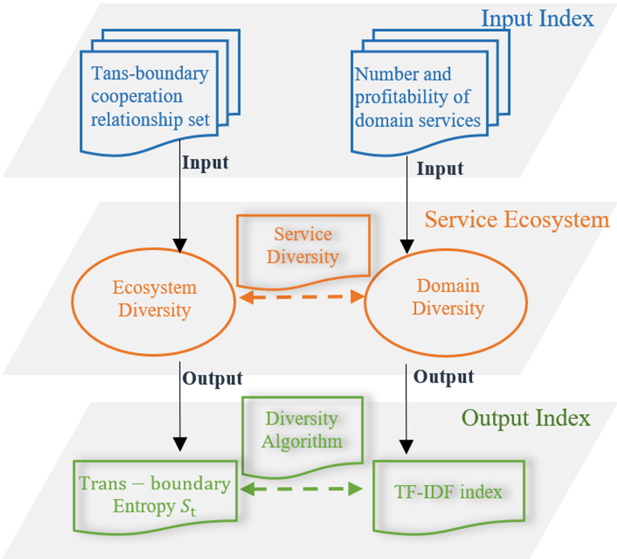

Fig. 3. Structure of diversity measurement algorithm.

types that may exist in the system. And calculate the trans-boundary entropy S_t of the service ecosystem (Fig. 3).

$$S_t = \sum_{i=1}^{D} \left[-\left(\frac{N_{it}}{N_t} \right) \log \left(\frac{N_{it}}{N_t} \right) \right] \tag{14}$$

where D is the trans-boundary set of the service ecosystem, N_{it} is the number of services that have i trans-boundary at t time, N_t is the number of all services at t time, and the base of the logarithm is 2.

4.2 TF-IDF Index

Domain diversity refers to the number of domains in the service ecosystem and the proportion of various domains in the system. Maintaining balance and stability in all areas of the service ecosystem is very important for the development of the service ecosystem. In this paper, the TF-IDF algorithm, a common weighting technology for information retrieval and data mining, is used to calculate the proportion of various domains in the service ecosystem. The higher the TF-IDF value in a domain, the larger its proportion in the service ecosystem. The more unstable the TF-IDF value of a system is, the less stable the development of the system is. Compared with counting the number of services in the service system, using a weighting technology can help us to observe the size of the domains in the ecosystem more intuitively and clearly. The TF-IDF index can be evaluated by the following equation

$$TFIDF_{ij} = TF_{ij} * IDF_i \tag{15}$$

where $TFIDF_{ij}$ is the TF-IDF index of the i domain at j time of the ecosystem, TF_{ij} is the proportion of the i domain at j time, and IDF_i is the weight value of the i domain.

TF_{ij} can be calculated by the following formula

$$TF_{ij} = \frac{v_{ij}}{v_j} \tag{16}$$

where v_{ij} refers to the sum of the total value of services in the i domain at j time, and v_j is the total value of all services at j time in the service ecosystem.

The weight value of domain i, IDF_i, can be calculated by this formula

$$IDF_i = \log_5 \left(\frac{\sum_{j=1}^{j=T} N_j}{\sum_{j=1}^{j=T} N_{ij}} \right) \tag{17}$$

where T is the time for the evolution of the service ecosystem, N_j is the total amount of all services at j time, $\sum_{j=1}^{j=T} N_j$ is the sum of the number of services in all periods, N_{ij} is the number of services in the i domain at j time, and $\sum_{j=1}^{j=T} N_{ij}$ is the sum of the number of services in i domain in all periods.

5 Construction of Computational Experiment and Result Analysis

By modeling the main elements of the service ecosystem, we can formulate a computational experiment platform to simulate the trans-boundary evolution mechanism of the service ecosystem [15]. In this section, we will analyze the impacts of trans-boundary services based on the experiment data and conduct a case study of Alibaba Group.

5.1 Construction of Computational Experiment

This experiment is based on the SETE model. In the service ecosystem, user demand and services are the main participants in interactive activities. Therefore, we built an agent-based model involving user demands and services on the Repast Symphony platform.

We set two experiments, the experimental group and the control group. Both of the two experiments set the same service ecosystem environments: each of the ecosystems comprises 3 domains, and the initial amount of services in each domain is 30, 20, 15 respectively. In order to facilitate the calculation and comparison of experimental data, all parameters are reduced in proportion to the actual data. Meanwhile, we randomly design invocation relationships in the domain. Apart from this, the experimental group added the trans-boundary evolution mechanism. When the service perceives a certain amount of trans-boundary demands in the system, the service will choose whether to try to trans-boundary integration based on its current income situation and value situation. By comparing the results of the two groups, we can observe the impact of the trans-boundary mechanism on the service ecosystem. Both ecosystems run 50 ticks.

Construction of Demand Agent. Demand is an important factor affecting the service evolution. And it can directly affect the survival of the service. We can make rules for demand agents (such as the number and type of demand agents) to model the trend of various market fluctuations. The structure of the demand agent is shown in Table 1.

Table 1. Attributes of the demand agent

Attributes	Description
$DemandCategory$	It represents the type of this demand. It describes the functions that the user needs the service to provide, including the input information and the desired service effect
$DemandVolume(t)$	It represents the current amount for this demand. The current volume of a kind of demand is affected by the growth trend of the demand and the supply ability of services
$DemandPrice$	It represents the market price of this type of demand. The value range for different types of services is $N(10, 4)$
$IncreaseTrend(t)$	It represents the increasing trend of demand. The growth trend of demand can be divided into rigid growth and non-rigid growth. The demand growth rate x for rigid growth per unit time follows a normal distribution: $x \sim N(\mu, \sigma^2)$, where μ determines the range of demand growth and σ^2 determines the intensity of demand growth. The demand growth rate y for non-rigid growth per unit time follows a uniform distribution: $y \sim U(a, a + b)$. In our experiment, the value range of μ and a is $[100, 200]$, and the value range of σ and b is randomly generated between $[10, 20]$

Construction of Service Agent. Service is the carrier of the value network in the service ecosystem and the basis for studying the mechanism of trans-boundary evolution. We construct the service agent according to the Definition 2.1. Service attributes include semantic attributes, value attributes, and interaction behaviors. The semantic and value attributes of the service agent are shown in Table 2, and the interaction behaviors are shown in Table 3.

5.2 Analysis of Computational Experiment Results

Analysis of Experimental Group Results

Table 2. Semantic and value attributes of service agent

Attributes	Description
$SemDescription$	It represents the semantic attributes of a service. It uses key words to describe the function-related parameters of the service, including inputs, outputs, preconditions, and effects. The service uses keywords to match corresponding needs and invoke other services
$Cost$	It represents the necessary cost of this service. It is distributed randomlylow(1), middle(2), high(3)
$QoS(t)$	It represents the current performance of this service and describes the quality of the service. The quality of the service range is $N(3,1)$
$Value(t)$	It represents the value currently owned by the service agent, as shown in Formula 4
$Vison$	It represents the range of information available to the service agent. The larger the range, the more likely it is to capture user needs and partners
$MovePace$	It represents the moving distance of the service per unit time in the service ecosystem. The larger the distance, the more sensitive the service
$MaxDemandNum$	It represents the total number of calls to the service in a unit of time. This attribute may affect whether subsequent user choose this service

Table 3. Behaviors of service agent

Behaviors	Description
$DealOrder$	When the service agent finds a demand that meets its business scope, the service moves to the location of the demand, provides the service for the demand, and obtain value
$Reproduction$	When the service's value reaches a certain range, the service will generate sub-services to expand the scope of the service or improve its service capabilities. The attributes of the new sub-service will be affected by inheritance and mutation. After the parent service generates a child service at time t, its value will change as follows: $V_{parent}(t+1) = V_{parent}(t) - V_{child}(t)$ (18)
$Cooperation$	When the service itself cannot meet the user's needs, it will complete the current demand by invoking other services and pay the invoking fee
$Transboundary$	Services achieve innovation through trans-boundary integration. Trans-boundary service can create value that cannot be created by single-domain service. The value of trans-boundary service is shown in 8

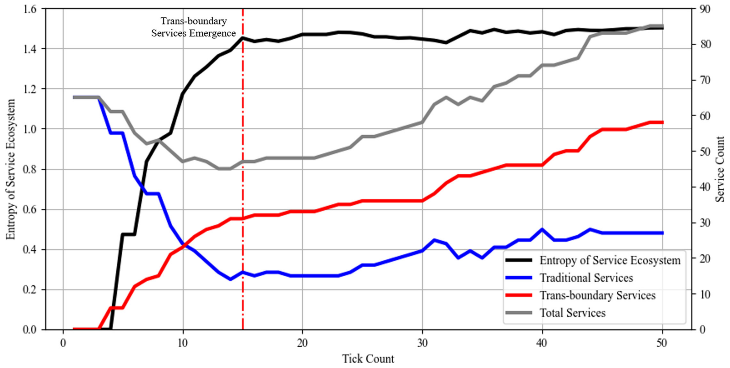

Fig. 4. Trans-boundary entropy and number of services in the experimental group.

Impact of Trans-Boundary on S_t Index. The impact of trans-boundary services on trans-boundary entropy S_t is shown in the black line in Fig. 4, and the axis is on the left. The other three polylines are the amount of single domain services and cross-domain services and the total number of services in the system over time, and the axis is on the left. In the trans-boundary service generation stage (Tick $\leq$ 15), services break through the domain boundaries to integrate and form trans-boundary services. This led to explosive growth in trans-boundary relationships in the service ecosystem. St of the ecosystem has improved significantly in a short time and reached a peak at tick = 15. After the generation of trans-boundary services (15 < tick $\leq$ 50), the ecosystem adapts to the generation of trans-boundary services and continuously adjusts the relationship structure, but there is no longer a large number of new trans-boundary services produced. Therefore, the S_t index has not changed significantly. At the same time, the growth in the number of trans-boundary services has slowed, and the number of services in a single domain has also slowly recovered. This is because the supply of trans-boundary services in the service ecosystem has reached saturation, and the market structure is changing to accommodate these new services. In the end, the number of trans-boundary services and the number of single-domain services is balanced, and the service ecosystem structure is also stable.

Impact of Trans-Boundary on TF-IDF Index. It can be found in Fig. 5 that the time when the TF-IDF index of each domain and the trans-boundary entropy S_t of ecosystem reach stability is very different. In the initial stage of the service ecosystem (tick $\leq$ 3), there were only three primitive domains in the service ecosystem, each occupying a certain proportion. In the stage of trans-boundary service generation (tick = 15), in order to meet the growing trans-boundary demand of users, a large number of services tried to cross the boundary. The TF-IDF index of the new domain reached its peak in a short time, and the supply of trans-boundary services reached a saturated state. However, in the stage of service ecosystem reconstruction (15 < tick $\leq$ 45), because the service supply is greater than the user demand, some services are difficult to make a

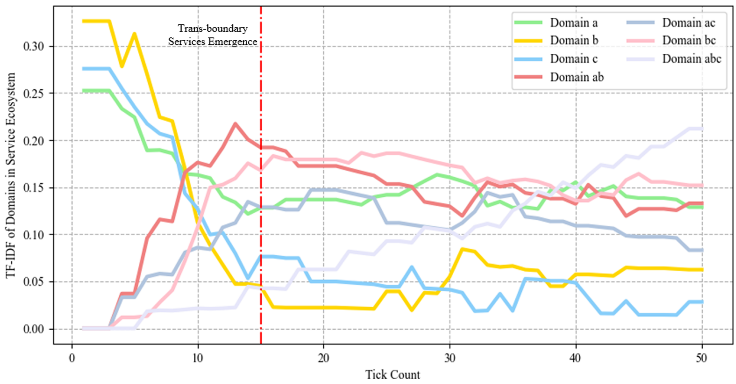

Fig. 5. TF-IDF index of domains in the experimental group.

long-term profit. Some services cannot continue to innovate, causing their development to stagnate or even die, which has caused the proportion of emerging trans-boundary domains in the market to decline. At last $(45 < \text{tick} \leq 50)$, the ecosystem gradually generates a new stable value network, and the fluctuation of TF-IDF index in various domains has slowed. The supply of various services in the ecosystem and the needs of users have reached a balance, the structure of the ecosystem has also returned to stability, and the process of trans-boundary evolution has ended.

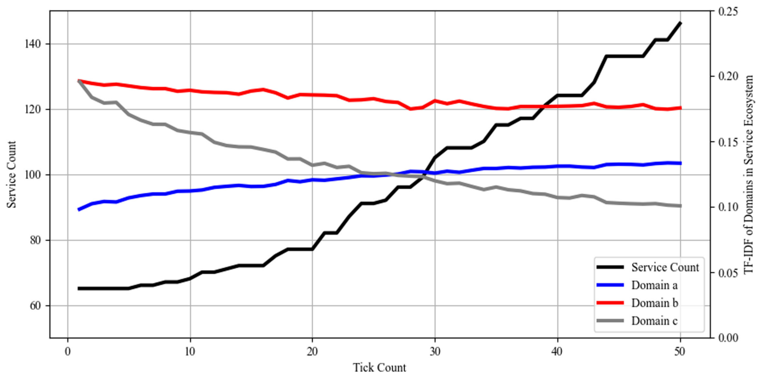

Fig. 6. Number of services and TF-IDF index of domains in the control group.

Analysis of Control Group Results. The black polyline in Fig. 6 is the number of services in the system, and the axis is on the left. The other lines are the TF-IDF index of the three domains, and the axis is on the right. The control group lacks a trans-boundary mechanism, so there is no trans-boundary relationship and trans-boundary entropy. Compared with the experimental group, The TF-IDF index in various domains have no obvious periodic fluctuations because of the lack of trans-boundary phenomenon. Due to the gap between the initial parameter setting and the actual demand in domains, the TF-IDF index in each domain has developed steadily and slowly. The service ecosystem has developed steadily and the number of services has increased steadily. The structure of the service ecosystem has remained stable.

5.3 Case Study

The key feature of the trans-boundary evolution model of the service ecosystem is that the S_t index and $TF-IDF$ index are asynchronously balanced. According to this characteristic, we can measure the degree of trans-boundary evolution of the service ecosystem. In order to verify the validity of the SETE model, we select a specific service ecosystem (Alibaba Group) as a case study. The data is based on the 2014–2019 quarterly performance reports released by Alibaba Group. The performance reports record the quarter revenue of each domain and the strategic investment of Alibaba Group over the four years. Alibaba Group began to enter the local customer service domain through a strategic joint venture in January 2015. And in May 2015, it was announced that the establishment of the Cainiao logistics service. Over the past four years, Alibaba Group has continuously adjusted its investment scale and business structure, and finally achieves positive income in these two domains, and has a certain share in the Chinese market. We calculated the S_t and $TF-IDF$ index of Alibaba Group in four years according to the algorithm in Part C of Sect. 3 as shown in Figs. 7 and 8.

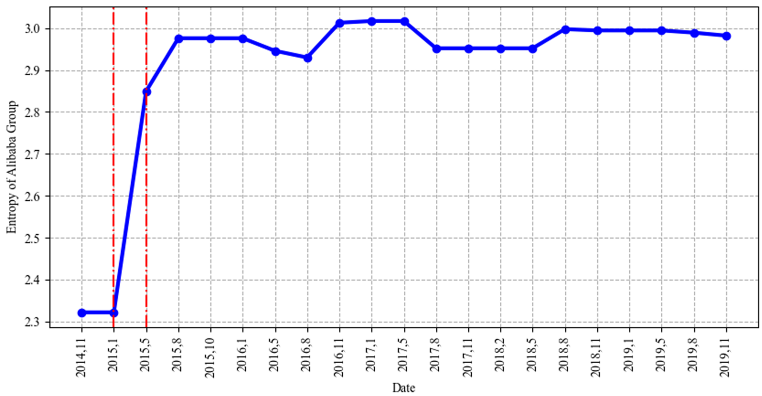

Fig. 7. Trans-boundary entropy of Alibaba Group.

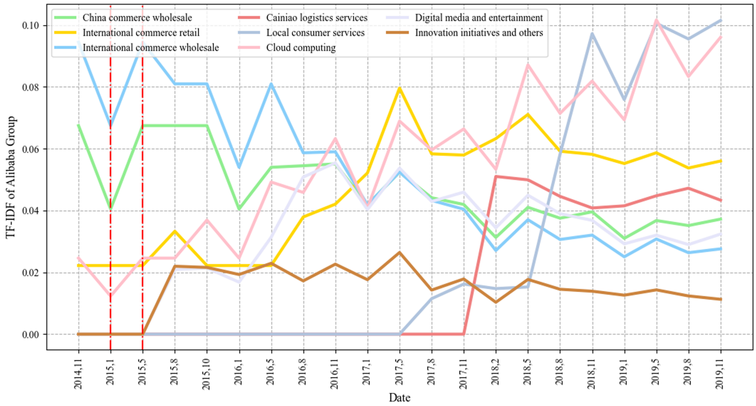

Fig. 8. TF-IDF index of Alibaba Group.

The results of Alibaba Group's diversity measurement are similar to the experimental group. Figure 7 is the change of the trans-boundary entropy of Alibaba Group in each quarter. It can be found that after the Alibaba Group announced its entry into the domain of local consumer services and Cainiao logistics services, its S_t index has increased significantly and remained at a high level since then. Figure 8 shows the TF-IDF index of the Alibaba Group in each quarter, except for the main retail sector in China. It shows that the TF-IDF values in all domains of the Alibaba Group have been affected after they began the trans-boundary industries. However, it was not until 2017 that the two trans-boundary domains began to occupy a certain weight and reached stability in 2019. Therefore, the SETE model is effective for studying the trans-boundary impact on the service ecosystem.

6 Related Work

In recent years, research on trans-boundary services has gradually emerged. Wu et al. proposed the theory of crossover service [17]. Crossover service emphasizes the phenomenon of crossover and integration between services in the modern service industry at the commercial level. Trans-boundary service emphasizes communication among domains by service integration at the web service level [4]. Service composition [9] strictly constrains the set of candidate services in order to accurately invoke services, which is a common method for service cooperation to solve user needs. Xue et al. [18] proposed the concept of "service bridge" to evaluate the trans-boundary impact of the Internet model. Some studies have used complex network to analyze the evolution of services and service relationships. Wang et al. [14] proposed an impact analysis model based on service dependency. Fokaefs et al. [3] analyzed the evolution of WSDL documents of Web services through the VTracker differentiation algorithm to discuss the impact of service changes and development on service system maintainability.

At the same time, the growing development of the service ecosystem has attracted inclusive attention. Liu et al. [10] defined the service ecosystem as services, consumers, service providers, service platform operators, and communities affected by their surrounding environment. The basic units interact through service composition and invocation. Xue et al. [19] proposed a framework for the manufacturing ecosystem from the perspective of social learning evolution. Wu et al. [16] studied the interaction between value co-creation and service innovation in the service ecosystem. Yin et al. [11] proposed a conceptual framework for defining and measuring the health of the software ecosystem. However, research on the trans-boundary impact on the development of service ecosystems is lack. Our work not only analyzes the trans-boundary evolution mechanism of the service ecosystem, but also quantifies the impact of trans-boundary services on the ecosystem, and verifies the effectiveness of the framework through examples. This not only helps to understand the emergence and development of trans-boundary services, but also helps to build a more realistic model of the evolution of the service ecosystem.

7 Conclusion

This paper introduces the trans-boundary evolution mechanism of the service ecosystem, develops a measurement algorithm to quantify the impact of trans-boundary services on the diversity of the service ecosystem, and conducts case studies of Alibaba Group. Using the computational experimental system, we explore the entire process of trans-boundary evolution of the service ecosystem.

In our research, we defined the overall architecture and cross-border evolution process of the service ecosystem. By measuring the diversity of service ecosystems, we find that the generation of trans-boundary services will cause the overall complexity of service ecosystems to increase immediately. However, the proportion of emerging domains in the ecosystem will not reach stability at the same time. It will continue to be turbulent during the evolution period of the ecosystem and will not be stable until the ecosystem structure is stable. The emergence of trans-boundary services can have an impact on the diversity of service ecosystems, and it will take some time for the ecosystem structure to stabilize again.

Although the service ecosystem is dynamic and changeable, by modeling its key elements, it can help us better analyze the activities and evolution mechanisms of the service ecosystem. In the future, we will try to build a more comprehensive theoretical framework to track and predict the generation and evolution of trans-boundary services, and provide constructive opinions for the development of the ecosystem.

Acknowledgement. This work is supported by the National Key R&D Program of China grant No. 2017YFB1401201, the National Natural Science Key Foundation of China grant No. 61832014 and No. 61972276, the Shenzhen Science and Technology Foundation grant JCYJ20170816093943197, and the Natural Science Foundation of Tianjin City grant No. 19JCQNJC00200.

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