

AI empowers the construction of an internationalization path for foreign language services to assist the digital economy: The construction of a foreign language service community integrating government, industry, academia, research, and application

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Abstract: *In the internationalization of the digital economy, the efficiency and accuracy of cross-language information flow constitute a key bottleneck. Traditional foreign language service models, due to fragmented agents and insufficient technical adaptation, struggle to meet the demands of high concurrency and heterogeneity. Based on the concept of a foreign language service community, this study constructs an AI-empowered architecture: it establishes a multi-agent ecological cooperation mechanism (niche nesting, dynamic coupling, distributed trust); it designs a digital company matrix and infrastructure integration architecture (capability pedigree classification, heterogeneous integration of the semantic computing layer and the transmission network, lightweight gateway and service bus); and it forms a talent resource support system (skill stack iteration algorithm, generative AI training environment, cross-border knowledge distillation and transfer). This framework achieves the systematic integration of ecology, infrastructure, enterprise, and talent, providing a computable technical solution for foreign language services to support the internationalization of the digital economy*

Keywords: *Foreign Language Service Community; AI Empowerment; Ecological Cooperation Architecture; Digital Company Matrix; Knowledge Distillation; Internationalization Adaptation*

Introduction

In the process of digital economic globalization, the generation and conversion of multilingual content constitute the fundamental support for cross-border information flow. The existing foreign language service system suffers from structural deficiencies such as inefficient multi-agent collaboration, a disconnect between technical infrastructure and business needs, and lagging updates in talent capabilities, and thus language barriers have not been systematically resolved. A service community that integrates multiple agents, digital infrastructure, and dynamically adaptive talents is of critical significance for enhancing the language accessibility of the internationalized digital economy. Current research mostly focuses on single-point technologies such as neural machine translation or large language models, and lacks a framework that integrates the four dimensions of ecological cooperation, enterprise matrix, infrastructure, and talent support into a holistic design. This study takes the integration of government, industry, academia, research, and application as its organizational logic, proposes an AI-empowered path for constructing a foreign language service community, and creates innovations in the areas of ecological coordination mechanisms, integration architectures, and talent adaptation algorithms.

1. Ecological Cooperation Architecture and Coordination Mechanism of the Foreign Language Service Community

1.1 Nested Structure of Multi-Agent Niches and Value Symbiosis Model

In the AI-empowered foreign language service community, each participating agent occupies a differentiated niche based on its resource endowment and functional output. Language resource holders (e.g., multilingual corpus operators) reside in the foundational niche and are responsible for the collection and annotation of raw language data. Neural machine translation model providers occupy the technological niche and perform semantic encoding and decoding tasks. Domain experts and localization reviewers are positioned in the verification niche and carry out precision calibration of the generated translations. These niches are not arranged linearly but form a nested structure: the technological niche is embedded between the foundational niche and the verification niche, and it achieves layer-by-layer invocation and feedback loops through API interfaces. The stability of the nested structure depends on the energy flow rate among the niches, that is, the transmission efficiency and distortion control capability of semantic feature vectors between layers^[1].

The value symbiosis model is designed based on a reciprocal resource exchange mechanism. Each agent in its niche exports its own surplus resources (e.g., computational redundancy, annotated data, terminological assets) while simultaneously absorbing scarce resources provided by other agents to compensate for its functional deficiencies. This model introduces a nonlinear value allocation function, which measures niche contribution as a weighted combination of three parameters: node centrality, reduction in information entropy, and task completion latency. Through a recursive value feedback loop, the benefits obtained by each agent are positively correlated with its embedded depth within the niche, thereby suppressing free-riding behavior and forming a self-organized symbiotic stable state.

1.2 Dynamic Coupling and Resource Allocation Protocol Across Organizational Boundaries

The essence of cross-organizational boundary coupling is to decouple the internal operational processes of each agent from its external service interfaces, thereby achieving functional coordination under loose coupling. The dynamic coupling mechanism adopts an event-driven architecture: each agent publishes its own capability description file (a semantic service description encoded in JSON-LD format) and subscribes to state change events of other agents. When the load on a given agent exceeds a threshold or a node failure occurs, the coupling regulator triggers runtime reorganization and rebinds the service invocation chain based on the current network topology and task priorities. This dynamic coupling reduces the intensity of interface dependencies between organizations and allows the independent upgrade or replacement of a single agent without disrupting overall service continuity.

The resource allocation protocol is designed for three types of critical resources: corpora, computational nodes, and translation memory banks. The protocol adopts a distributed negotiation algorithm based on double auctions: a resource requester submits a bid with quality constraints (BLEU threshold, latency ceiling), and a resource provider broadcasts its available capacity and unit cost. The protocol incorporates a sealed-bid mechanism against strategic gaming and a second-price settlement rule to suppress malicious bidding behaviors. The allocation execution layer adopts a micro-batch processing mode, aggregates multiple requests within a short time window into resource scheduling units, and achieves load balancing with lightweight consistent hashing. This protocol completes the optimal allocation of resources without a central coordination node, thereby adapting to the burstiness and heterogeneity of foreign language service requests in digital economy scenarios.

1.3 Algorithmic Path for Distributed Trust Transfer and Collaborative Governance

Distributed trust transfer replaces the centralized authentication node and establishes a foundation for trustworthy interaction among agents through consensus algorithms. The trust model takes Verifiable Credentials as its core carrier: the historical service quality, response timeliness, and semantic fidelity of each agent are encoded as on-chain credentials, which are jointly signed by multiple independent verification nodes. The trust value is updated using a sliding window weighted average method, in which the weight of recent interaction results decays exponentially, thus enabling the trust model to respond quickly to behavioral drift. The trust transfer path is represented by a directed edge in the trust graph. When agent A needs to evaluate the reliability of an unfamiliar agent C, it can perform trust aggregation along the path $A \rightarrow B \rightarrow C$ in the trust graph. The aggregation function uses a combination of the geometric mean and a confidence decay factor to avoid excessive trust

amplification^[2].

The algorithmic path of collaborative governance transforms governance rules into executable smart contract logic. Governance parameters, including resource allocation weights, dispute resolution thresholds, and niche access conditions, are stored in the form of an on-chain parameter table. When an abnormal event is detected (e.g., consecutive translation quality falling below a preset threshold), the governance contract automatically triggers an arbitration process: it randomly selects several verification nodes to perform double-blind reviews on the disputed samples, and it combines this process with a reputation reward-punishment mechanism based on a multi-armed bandit to impose call frequency restrictions or temporary suspension on the violating agent. Algorithmic governance eliminates the subjective bias of manual adjudication, and its decision-making process is traceable and auditable, thereby forming a closed-loop adaptive governance system.

2. Integration Architecture of the Foreign Language Service Digital Company Matrix and Infrastructure

2.1 Digital Capability Spectrum and Matrix-Based Classification of Foreign Language Service Enterprises

The digital capability of a foreign language service enterprise can be characterized along two dimensions: the depth of automated processing and the granularity of domain-specific semantic adaptation. The depth of automated processing forms a continuous gradient, ranging from computer-assisted translation with translation memory (CAT+TM) to fully autonomous post-editing of neural machine translation (NMT), and further to context-aware generative translation based on large language models. The granularity of domain-specific semantic adaptation is divided into three levels: general corpus-driven type, vertical terminology base-constrained type, and real-time knowledge graph-injected type. By crossing these two dimensions, a digital capability matrix containing four ideal types is constructed: standardized batch processing type (low depth, low granularity), vertical precision matching type (low depth, high granularity), adaptive pipeline type (high depth, low granularity), and full-stack cognitive type (high depth, high granularity). Each type corresponds to a different enterprise technology stack and business model, and the matrix-based classification provides type labels for service registration and routing in the subsequent integration architecture.

This classification framework further introduces a dynamic evolution mechanism, meaning that the digital capability spectrum of an enterprise is not fixed but undergoes type migration based on its own business evolution and external technological shocks. The migration path is described by a capability transition probability matrix, in which the migration cost is jointly determined by the scale of existing data assets, the redundancy of personnel skills, and the lock-in effect of the infrastructure. For a full-stack cognitive enterprise, its capability characteristics include high-order functions such as multimodal input parsing, cross-lingual anaphora resolution, and emotional style transfer, all of which require deep binding with the semantic computing layer in the infrastructure. Thus, the matrix-based classification serves as a bridge connecting individual enterprise characteristics with the integration architecture design, guiding the interface specifications and resource reservation strategies to be deployed by each type of enterprise.

2.2 Heterogeneous Integration Design of the Semantic Computing Layer and Transmission Infrastructure

The semantic computing layer resides above the traditional transmission infrastructure and undertakes the task of converting raw language signals into structured semantic representations. This layer consists of three submodules: a multi-granularity word segmentation and dependency parsing module, a cross-lingual entity alignment and relation extraction module, and a context encoding module (a Transformer-based variant of the bidirectional encoder). These submodules are deployed on edge nodes in the form of microservices, and each module outputs high-dimensional semantic tensors. The transmission infrastructure (including the fiber-optic backbone network, 5G access network, and data center interconnection network) originally focused only on the physical and network layer exchange of data packets. The heterogeneous integration design requires embedding a semantic-aware scheduling unit within the transmission protocol stack. This unit parses the priority tags of the semantic tensors (e.g., real-time dialogue interaction has a higher priority than batch document translation) and accordingly adjusts the queue scheduling algorithm (using a weighted fair queue and a semantic

urgency function).

The heterogeneity of the integration architecture is reflected in the coordination of two heterogeneous resources: computation-intensive semantic parsing tasks and bandwidth-sensitive raw data transmission tasks share the same physical link without blocking each other. The design adopts a bidirectional decision-making mechanism of computation offloading and transmission prefetching: when the computational load of an edge node exceeds a threshold, it dynamically offloads the semantic parsing task to a cloud inference cluster, while the transmission link prefetches subsequent unprocessed language fragments; when network congestion occurs, it conversely retains the high-priority semantic task locally and transmits only the compressed semantic feature vectors. This mechanism is realized by solving an online convex optimization problem in a time-varying environment, with the objective of minimizing the weighted sum of end-to-end language service latency and semantic distortion rate, thereby forming an adaptive scheduling strategy for deep integration of semantics and transmission^[3].

2.3 Deployment Logic of the Lightweight Semantic Gateway and the Cross-Language Service Bus

The lightweight semantic gateway is deployed at the network edge, between the end users and the service bus. Its core functions include automatic source language identification, breakpoint detection and streaming segmentation of source language sentences, and health status probing of multiple backend service nodes. The lightweight nature is reflected in three aspects: a stateless design (session information is maintained by upstream clients or the downstream service bus), a slim model (only deploying language identification and word segmentation models, excluding full NMT or LLM), and binary protocol parsing (avoiding the redundant overhead of XML or JSON). The gateway adopts pipelined parallel processing: each arriving language package sequentially passes through the language identifier, the breakpoint detector, and the routing decision module. The routing decision is based on a cost function composed of the current load of service nodes, the semantic cache hit rate, and the coverage of the target language.

Cross-language service bus serves as the communication backbone connecting various foreign language service digital entities within the multi-company matrix. The bus adopts a publish-subscribe model and maintains a dynamically updated service registry, with each record containing a service identifier, a capability type label (corresponding to the matrix classification in Section 2.1), an input-output language pair, the current endpoint address, and SLA parameters. When the lightweight semantic gateway issues a request, the bus performs service discovery and composition orchestration: if a single service can satisfy the request (e.g., English-to-Chinese document translation), the bus routes directly; if multiple services need to be chained (e.g., speech recognition → machine translation → speech synthesis), the bus generates a directed acyclic graph execution plan based on topological sorting. The bus incorporates idempotency checking and a timeout retry mechanism, automatically removes unresponsive service nodes from the registry, and triggers replica instantiation. This deployment logic achieves elastic interconnection and functional coordination of the foreign language service digital company matrix without relying on a centralized coordinator.

3. Talent Resource Support System and Internationalization Adaptation Path

3.1 Dynamic Iteration and Adaptive Update Algorithm of the Skill Stack for Foreign Language Service Talents

The skill stack of a foreign language service talent consists of multi-level capability units: the bottom layer comprises linguistic knowledge (syntactic, semantic, and pragmatic rules); the middle layer comprises digital tool operation capabilities (CAT, NMT, and LLM invocation and debugging); and the top layer comprises cross-cultural pragmatic strategies (context adaptation, style transfer, and implicit information explication). The dynamic iteration of the skill stack is driven by external technological shocks and market demand shifts, while the traditional static capability inventory fails to cope with task domain drift. An adaptive update algorithm based on Bayesian knowledge tracing is therefore designed. This algorithm models each talent's capability state as a multi-dimensional latent variable, with observed variables being the completion quality scores and response latencies on different task types. The algorithm estimates the mastery probability of each capability unit through forward-backward recursion. When the mastery probability of a given capability unit falls below a dynamic threshold—determined by the distribution quantile of the peer talent group—the algorithm triggers an automatic update request for that unit and pushes the corresponding micro-learning module

and verification test.

The innovation of the adaptive update algorithm lies in its introduction of a transfer reinforcement learning mechanism, which uses the skill evolution trajectories of other talents in similar positions within the foreign language service community as source domain knowledge. The algorithm extracts skill co-occurrence patterns and failure transition probabilities from the source domain, and transfers them to the target talent's capability update model through maximum mean discrepancy regularization, thereby accelerating convergence and reducing the number of required direct assessments. The updated skill stack is written into the distributed trust storage in the form of Verifiable Credentials, enabling real-time querying by the resource allocation protocol in the ecological cooperation architecture. This algorithm keeps the talent's skills evolving synchronously with the semantic computing layer of the technical system, forming a closed-loop feedback between the talent resource and the digital infrastructure, thus preventing capability decoupling^[4].

3.2 Generative AI-Driven Immersive Corpus Training Environment

The immersive corpus training environment uses generative artificial intelligence as its content engine to construct high-fidelity cross-cultural interaction scenarios. The environment consists of three core components: a scene generator (multimodal context rendering based on a diffusion model), a dialogue agent (a virtual character driven by a large language model with configurable personality parameters and pragmatic styles), and a real-time feedback module (sentence-by-sentence evaluation of the learner's grammatical accuracy, pragmatic appropriateness, and response timeliness). The training environment no longer relies on pre-recorded fixed corpora but dynamically generates dialogue branches and contextual variants based on the learner's current capability level and training objectives. The generation process is governed by a set of constraints, including the target language, domain terminology density, cultural specificity index, and error tolerance threshold, ensuring that the difficulty gradient of the generated content matches the trainee's skill stack status.

The training effectiveness of this environment is quantified by the increment in pragmatic competence, defined as the reduction rate in the learner's pragmatic error rate on unseen scenarios between two assessments. The environment incorporates an adversarial data augmentation mechanism: a discriminator network distinguishes the learner's utterances from those of native speakers, and a generator network iteratively optimizes the realism and challenging nature of the generated scenarios accordingly. The immersive experience is delivered through a head-mounted display device and spatial audio, and the learner's eye movement trajectories, speech prosody, and response latency are collected as implicit feedback signals to fine-tune the complexity and interaction pace of subsequent scenarios. This training environment forms a closed-loop data connection with the skill stack update algorithm in Section 3.1: the capability assessment results output by the environment are directly fed into the adaptive update algorithm, and the new skill targets generated by the latter, in turn, drive the parameter adjustment of the scene generator.

3.3 Cross-Border Collaborative Knowledge Distillation and Migration Optimization Path for Multilingual Service Networks

Cross-border collaborative knowledge distillation addresses the problem of imbalanced resource distribution in multilingual service networks. High-resource languages (e.g., English, Chinese, Spanish, etc.) have access to large-scale parallel corpora and high-quality translation models, whereas low-resource languages (e.g., certain Southeast Asian or African languages) suffer from data sparsity and model underfitting. The knowledge distillation framework uses the soft labels (i.e., smoothed versions of the vocabulary probability distribution) output by teacher models of high-resource languages as supervision signals to train student models for low-resource languages. Cross-border collaboration is reflected in the distributed execution of the distillation process: multiple teacher models located in different regions (each maintained by local foreign language service digital companies) generate soft labels for the same batch of interlingua input, and the student model fuses these heterogeneous knowledge sources through a weighted voting mechanism, with the weights determined by the domain confidence of each teacher model and the linguistic proximity distance.

The migration optimization path further introduces a meta-learning strategy to enable the student model to acquire rapid adaptation capability on low-resource languages. The meta-learning stage simulates low-resource scenarios across multiple high-resource language pairs: it randomly draws a small number of samples from each high-resource language as a support set, trains the model's ability

to quickly fine-tune on that language, and a meta-optimizer updates the initial parameters of the model. When transferring to a real low-resource language, only a very small amount of labeled data is required to reach an usable level. This path collaborates with the lightweight semantic gateway and the cross-language service bus: when the service bus receives a request for a low-resource language, it preferentially calls the lightweight student model distilled through cross-border collaborative knowledge distillation, and if the confidence level falls below a threshold, it falls back to multi-hop translation (relaying through an intermediate high-resource language). The entire knowledge distillation and migration process does not rely on a central corpus, and each participant exchanges only soft labels rather than raw data, thereby satisfying the distributed trust and resource allocation constraints within the ecological cooperation architecture.

Conclusion

This study constructs an AI-empowered foreign language service community architecture from four dimensions: ecological cooperation, digital company matrix, infrastructure, and talent resources. The multi-agent niche nesting and value symbiosis model, the cross-organizational dynamic coupling protocol, and the distributed trust governance algorithm form a collaborative mechanism for a loosely coupled ecology. The digital capability spectrum classification, the heterogeneous integration of the semantic computing layer and transmission infrastructure, and the lightweight gateway and service bus achieve the integration of the enterprise matrix and infrastructure. The skill stack iteration algorithm, the generative AI training environment, and the cross-border collaborative knowledge distillation and migration strategy ensure the synchronous evolution of talent and digital systems. Future directions include cross-regional model collaborative training based on federated learning, multimodal semantic and infrastructure integration paradigms, and a dynamic meta-learning framework for low-resource languages, aiming to drive the theoretical architecture toward practical system evolution.

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