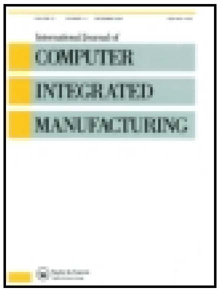

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Developing silicon intellectual property E-trade mechanisms for system on chip design and integration

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Developing silicon intellectual property E-trade mechanisms for system on chip design and integration

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The integration of IC design and manufacturing (IDM) is a major trend in the modern management paradigm of the semiconductor supply chain. In order to shorten the time-to-market for complex system-on-chips (SoC), the trade and reuse of silicon intellectual properties (SIPs) for fast IC design becomes a critical success factor for semiconductor IDM. In this research, intelligent mobile agents and fuzzy evaluation models are built into a knowledge services and trade platform (KSTP). The mobile agent behaviour model is used for knowledge acquisition and negotiations between sites of SIP providers, buyers and intermediators. The agent-based KSTP considers time, cost and precision of acquiring SIP information needed for SoC design and fabrication. For trade partner matching, fuzzy evaluation models are developed to consistently suggest suitable partners for trades under different circumstances. The ultimate goal of the research is to enable autonomous, dynamic and collaborative SIP exchanges and trades in the global value chain of semiconductor industry.

Keywords: Silicon intellectual property (SIP); System on chip (SoC); Knowledge services; E-trade; Mobile agent

1. Introduction

Designers of systems-on-chips (SoC) face a growing number of decisions concerning the design and re-use of intellectual property blocks (often called 'silicon intellectual property' or 'SIP'). These blocks include processing cores, memory, user-defined logic, interfaces to the outside world, buses and so on. SoC designers must determine how much of a previous design can be used in a new chip and, most importantly, which design components might be purchased and quickly integrated into the overall SoC architecture to save time to market. Integrating existing SIP cores into new designs has become an essential phrase of the SoC design process. Different types and grades of SIP must be placed together, integrate into the overall system design and match the design specifications (Abbes *et al*. 2004). During the 1970s, when electronic devices demanded less sophisticated designs, monolithic companies controlled all aspects of electronic device design, integration, manufacturing, and IP management. Dis-integration of the integrated chip (IC) industry began in the 1980s–1990s when the cost of a semiconductor fabrication plant (called IC fab or foundry in short) began to rise into the scale of multi-billion US dollars, forcing few foundries specializing in serving fabless companies or system design houses. Nonetheless, virtual re-integration between foundries, third-party IP vendors, fabless companies, and system design houses has become the trend in the 2000s with internet connections being formed to link IP libraries, design tools and partners so that SIP can be readily traded and reused in complex SoC design to reduce time to market.

SIP is classified as soft, firm or hard IPs depending on the level of proved implementation (Hunt and Rowson 1996). Soft IP components, the most portable IPs, represent

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algorithms and architecture specified in register-transfer level (RTL) code. Firm IP components are soft IP components with additional simulation runs for performance, area, and power demand. Finally, hard IPs are less portable since they are tested and verified in a fixed physical silicon form. Chiang (2003) further notes that many foundries offer three grades of hard IP to clients that cannot afford their own chip-manufacturing facilities. The one-star pre-silicon grade (referred to as firm IP above) has an architecture tested via simulation. A three-star foundry verified grade has IP verified for a specific process. Finally, a five-star production grade means that the IP is production proven and completely tested.

Currently, there is a significant gap between SoC manufacturability and design-ability (Chang and Trappey 2003). According to Chiang (2003), IC design productivity (transistors per staff per day) is growing at a rate of about 21% per year, but the number of IC logic transistors per chip is increasing by about 58% per year. For example, today's cellular phone designs are very complex with functions of multi-band and multi-mode supports such as Bluetooth, GPS and WLAN. During SoC design and production, many problems (performance, reliability and yield limitations) are discovered (Krenik *et al.* 2005). In order to reduce design time, several approaches have been studied to enable SIP reuse and synthesis. For SIP reuse, it is assumed that SoC designs can be assembled from SIP blocks to quickly facilitate the speed of design (Gajski *et al.* 2000). Thus, the reuse and public trades of a variety of SIPs are considered to extend the life and investment returns on component level IC designs (Lee *et al.* 1999). Thus, developing an electronic trade (e-trade) platform to facilitate the SIP commercialization is a means to boost the global competitive advantage of the SIP/IC design community.

This research demonstrates the design and development of an intelligent knowledge service and e-trade platform for SIP search, acquisition and exchange across the internet. The knowledge service and e-trade platform (KSTP) enhances the dynamic SIP information collection and exchange using mobile agent technology. Many researches are now using intelligent agent-based technology to automate trade process and enhance trade performance (Trappey *et al.* 2006). Autonomous agents have a degree of control over their own activities, can make complex trade decisions, and can negotiate with other agents. Mobile agents have the unique ability to migrate from one system to another in a network environment. The KSTP also provides matching mechanisms for SIP trade. SIP buyers and sellers post their requirements and the platform's matching agents are sent out to search and evaluate suitable trading partners for SIP sales negotiation. Given design engineers expert input, we develop fuzzy decision models and embed the models into mobile agents which then evaluate and rank potential buyers and sellers. The research background and literature, covering SIP malls, software agents, mobile agent technology and applications are provided in section 2. Section 3 describes the key methodologies for KSTP development. In section 4, the process models of the prototyping system are described. The discussion covers the implementation of mobile agent behaviour processes for SIP inquiry, collection, monitoring and fuzzy trade matching. We also extend the discussion to describe the KSTP's asynchronous and autonomous features and compare these features to previous research. Section 5 presents the research contribution and outlines future research directions.

2. Literature review

For SIP exchanges/trades over the Internet, there are ways to represent technical descriptions so that buyers from around the world can quickly evaluate the benefits and compatibility of SIP designs. Researchers have demonstrated that SIP databases (Coors *et al.* 1999) and web portal infrastructures (Schindler *et al.* 1999) facilitate online trade. Further, IP malls, electronic marketplaces, and libraries which provide access to well organized categories of designs are helping engineers and designers reduce product R&D time (Trappey *et al.* 2002). In addition to providing a search engine, the emerging electronic marketplace for SIP is providing smarter tools and services to help support negotiation and trade decision making. Customer service is a critical part of the marketplace offering, as is the ability to provide legal assistance, negotiate trade agreement, and configure contracts through the use of templates that model standard business practices (Chang and Trappey 2003).

The IP trade process workflow begins with the creation of the intellectual property at the IP provider's worksite. Each component that has been verified for design and reuse is considered a stock-keeping unit (SKU). The SKUs require standardized business processes for trade. The business process include keeping stock, catalogue/category management, protection of intellectual assets, and managing IT tools used to convert different portions of the property into formats requested by buyers and distributors. We can treat an IP mall as a self-contained virtual trade zone containing various business partners that are linked by common passageways. All of the players in the mall co-exist with a shared purpose, to engage in the trade of IP and the provision of related services. Nonetheless, there are various business decisions to be made during the SIP trade processes, which are usually not addressed and automated in the IP mall settings, e.g., evaluating suitable SIP and choosing SIP providers.

A software agent is a type of computer software that executes a specific task with unique features. They are autonomous, goal-oriented, collaborative, flexible, self-starting, communicative, adaptive and mobile (Maamar 2002). Beside these features, Wooldridge (1995) describes software agents as having social ability and responsiveness for self-adjustment during collaboration. In recent years, researchers have focused on enabling dynamic communication, collaboration, and group decision making using agent technology. Table 1 provides a summary of the agent-based research literature. Some research focus on construction of software agents with autonomous mobility that migrate from one host to another via the network (Papaioannou and Edwards 1999) and accomplish specific tasks. Telescript, the first mobile agent framework developed by General Magic, Inc. (White 1994), enables agents to migrate to the remote host over the network. Several Java-based environments have been developed over the past ten years to create mobile agents. For example, the IBM Japan research group has developed aglet technology as a framework for constructing mobile agent applications (Lange *et al.* 1998). This research deploys the aglet agents from the KSTP which travel to remote hosts and execute SIP trade related activities such as acquiring information and evaluating trade partners.

As for the research related to fuzzy decision model, an early fuzzy evaluation model was developed by Wang (1997) to model imprecise preference structures of decision making in conceptual design based on the outranking approach and fuzzy preference relations. The approach presented was useful in the imprecise and uncertain design environment. Li (1998) developed a simple and efficient fuzzy model and solution algorithm for multiple criteria decision problems involved in a fuzzy environment. Further, Hwang and Yu (1998) defined a fuzzy methodology and a computer model for guiding the selection and resource allocation of R&D projects. An extension to fuzzy decision making was demonstrated by Wang (2000) with a sophisticated solution for the machine selection problem. However, it was not until 2006 that researchers developed one of the first trade related fuzzy models. Kumar *et al.* (2006) proposed an integer programming for vendor selection with multi-objectives such as cost minimization, quality maximization, and maximization of on-time-delivery. Their approach provides a decision tool that facilitates vendor selection and their quota allocation under different degrees of information vagueness.

3. Intelligent agent and fuzzy models for KSTP system design

SIP is commercially distributed during the lifecycle of IC design and fabrication. When IC designers are designing new chips at a host site, task-specific mobile agents are dispatched by the host to SIP providers' sites to collect information. The remote sites are the IC manufacturers, SIP designers and SIP distributors. After the data collection agents return with data, the documents are stored at the host site for reference. At a later stage, the KSTP matches the buyers and sellers to facilitate SIP trade. Both buyers and sellers maintain data and fuzzy membership functions on the system. The broker agent (or intermediary) makes suggestions based on the fuzzy evaluation model and dispatch agents to deliver the message to the buyers and sellers. The four players interacting on the KSTP are the IC

Table 1. Related applications of agent technologies.

Authors	Research topics	Mobile agent (V)
Fischer *et al.* (1996)	Intelligent agent framework for operations of virtual enterprises	
Rothermel *et al.* (1997)	Mobile agents for handling business uncertainty	V
Falchuk and Ahmed (1997)	Applications of mobile agents for information access, interaction and retrieval	V
Liu (1998)	Support strategic environmental scanning and interpretation	
Sugumaran and Bose (1999)	Support complex data analysis, mining and decision making	
Chen *et al.* (2000)	Automate tasks in e-commerce applications	
Domazet (2000)	Enable engineering collaboration in inter-enterprise design chains	
Zha (2002)	Concurrent intelligent design and assembly planning	
Anumba *et al.* (2002)	Collaborative engineering structure design	
Xu and Wang (2002)	B2B workflow monitoring	
Shih *et al.* (2002)	Recommendation systems for e-commerce applications	
Mitkas *et al.* (2003)	Coordinate tasks for concurrent engineering using intelligent agent and data mining techniques	
Beetz *et al.* (2004)	Support collaborative architectural design	
Huang (2004)	Collaboration in modular product design	
Jia *et al.* (2004)	Coordinated product development and production	
Liu *et al.* (2004)	Dynamically create and manage design tasks in distributed and ever-changing environment	
Tang (2004)	Integrate die-maker's activities in customized product development process	
Trappey *et al.* (2004)	Use mobile agents to coordinate online activities for global logistics management	V
Madhusudan (2005)	Agent-based coordinated product design workflows	
Trappey *et al.* (2006)	Propose a mobile agent framework for SIP trades (foundation of this research)	V
Ying and Dayong (2005)	The e-commerce applications for third-party logistics management	

designers (i.e. SIP buyers), SIP providers (i.e. SIP sellers), IC manufacturers (i.e. SIP users) and matching brokers. The operating model describes the detailed interactions and behaviours among the KSTP roles. These interactions consist of SIP information inquiry, acquisition status monitoring and trade partner matching. The modules are defined below.

1. *SIP inquiry module*. This module enables external communication. After submitting the keywords for search, users invoke the inquiry agents to collect SIP via the Internet from remote sites. The module includes the sub-module of receiving agents operating on the SIP providers and IC manufacturer locations. The receiving sub-module enables the mobile agents to acquire SIP data and documents from the remote hosts.
2. *SIP acquisition monitoring module*. KSTP users logon to the monitoring module to receive SIP status reports. When the monitoring agents complete the tasks, users review and download the SIP documents from this module. The module also reports the work-in-progress of agents at the remote or host sites.
3. *SIP trade partner matching module*. This module works for IC designers, SIP providers, IC manufacturers and matching brokers. The matching server is located at the site of a matching broker. The subsystems are located at the other sites. Both buyers and sellers maintain their trading data and membership functions as a decision model at the matching broker site. After the matching process is completed, the matching agents return to the original hosts and update the suggestion list in the database.

3.1. *Behaviour models of mobile intelligent agents on KSTP*

There are two mobile agent behaviour models developed for the KSTP, i.e. the SIP inquiry behaviour model and the SIP trade matching behaviour model. First, in order to improve asynchronous SIP search efficiency, the inquiry model is regarded as a collaborative, real-time procedure that uses mobile agents to authorize the remote tasks. After each agent is dispatched to the remote host, it independently starts the request. Figure 1 depicts the concept of independent and parallel execution and collaboration. When mobile agents complete tasks at the remote host, they will report back to the manager agent at the home host and deliver the SIP to the inquiry module. The local manager agent continuously monitors task performance and eventually declares the mission accomplished after all mobile agents return home.

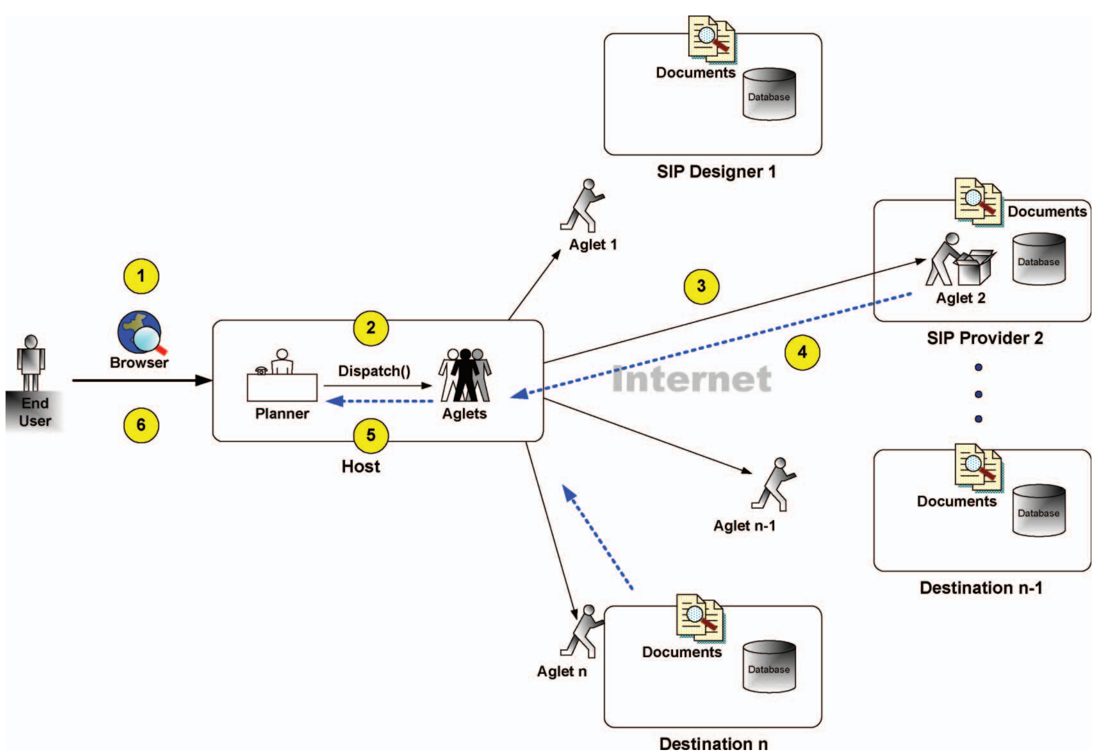

Figure 1. The concept of asynchronous and autonomous remote inquiry, collection and status reporting.

Mobile agents serve as coordinators in the SIP matching process. Both buyer and seller decide whether to join the matching process conducted by the agent-based matching server. The deadline set by the administrator signals the broker agent to begin the process and the system locks itself to prevent modification of the buyer and seller data. The broker agent retrieves the buyers' and sellers' matching data from database, and calculates the performance indices based on the membership functions defined by each buyer and seller. Next, the broker agent assigns mobile agents to deliver trading suggestions to the remote hosts of buyers and sellers. Figure 2 depicts the concept of the agent behaviour model for SIP matching.

3.2. *Fuzzy evaluation model for buyer-seller matching*

When an IC design company decides to include newly purchased SIP, it is best to use a consistent matching function that models established business processes. In this research, fuzzy sets theory is utilized to form the evaluation model for the matching process. The matching model helps the buyers and sellers using an evaluation model derived from trade experience with partners. The logic is that the broker evaluates buyers and sellers using pre-defined membership functions. The key performance indicator (KPI) measures the strength of each trading partner across a multidimensional scale (tables 2 and 3). The KPI values for all potential buyers and sellers are derived from managers to model the company's preferences using fuzzy membership functions. Three membership functions map KPI values to the membership values. As shown in figure 3, KPI (1) fits well with membership function (a) because the higher the offering price, the less preferred of the seller is. Nonetheless, KPIs (6), (8), (14) and (16) are well mapped to function (c) because, sometime, SIP companies of the right size and maturity (not too big/small nor too young/old) are preferred by the buyers. Finally, the other KPIs ($2\sim5$, $7\sim13$, $15\sim16$) are represented in membership function (b).

The overall performance value of the jth trading partner is defined as the weighted combination of all membership values $(1)\sim(8)$ when j is a seller or $(9)\sim(16)$ when j is a buyer.

$$\text{Performance}_j = \frac{\sum_{i=1}^{m} f_i(x_{ij}) \cdot w_i}{\sum_{i=1}^{m} w_i}, \quad 0 \le \text{Performance}_j \le 1$$

x_{ij}: the ith index value of the jth trading object;
w_i: the weight of the ith index;
$f_i(.)$: the membership function of the ith index.

4. KSTP process models

The KSTP prototype is implemented following the functional structure as shown in figure 4. For SIP document search, collection and trade negotiation, SIP documents are

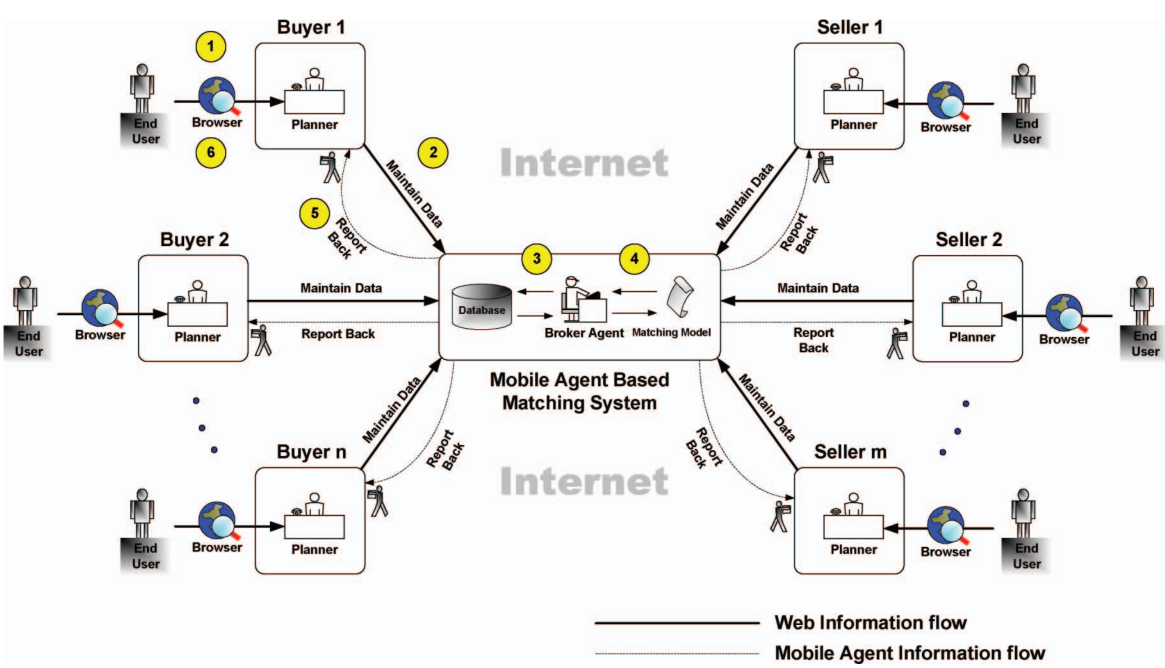

Figure 2. The agent behavioural model for SIP matching.

Table 2. The SIP seller's KPIs under the buyer's consideration for potential sellers.

Category	Concerns of SIP buyers	Seller key performance indicators (Seller KPIs)
1	Seller's sales strategy	(1) Seller's offering price (2) Seller's price discount level
2	Seller's R&D capability	(3) Seller's accumulative IPs for sales (4) Seller's number of granted patents
3	Seller's business performance	(5) Seller's revenue (6) Seller's capital (7) Seller's earnings per share (EPS) (8) Seller's company maturity (Years)

Table 3. The SIP buyer's KPIs under the seller's consideration for suitable buyers.

Category	Concerns of SIP Sellers	Buyer KPIs
1	Buyer's procurement strategy	(9) Buyer's purchasing price (10) Buyer's start-to-build (STB) IC quantity
2	Buyer's IP demands	(11) Buyer's annual IC sales quantity (12) Buyer's IP purchasing quantity
3	Buyer's business performance	(13) Buyer's revenue (14) Buyer's capital (15) Buyer's EPS (16) Buyer's company maturity (Years)

formatted using the standard XML DTD for IP metadata schema definition as follows:

```
<!ELEMENT contents ( function, keyword+, ip, company ) >
<!ELEMENT function ( #PCDATA ) >
<!ELEMENT keyword ( #PCDATA ) >
<!ELEMENT ip ( ipname, pn, verification, technology, description, datasheet, qualified ) >
<!ELEMENT company ( companyname, email, phone, fax, url ) >
      <!ELEMENT ipname ( #PCDATA ) >
  <!ELEMENT pn ( #PCDATA ) >
  <!ELEMENT verification ( #PCDATA ) >
      <!ELEMENT technology ( #PCDATA ) >
  <!ELEMENT description ( #PCDATA ) >
  <!ELEMENT datasheet ( #PCDATA ) >
  <!ELEMENT qualified EMPTY>
<!ATTLIST qualified type ( Hard | Soft ) #REQUIRED >
  <!ATTLIST qualified level ( Foundation | Standard | Star ) #REQUIRED>
<!ATTLIST qualified verification ( Gold | Silver | Bronze | In-development ) #REQUIRED >
  <!ELEMENT companyname ( #PCDATA ) >
  <!ELEMENT email ( #PCDATA ) >
  <!ELEMENT phone ( #PCDATA ) >
  <!ELEMENT fax ( #PCDATA ) >
<!ELEMENT url ( #PCDATA ) >
```

4.1. Agent-based SIP inquiry and acquisition monitoring system

The buyers or sellers logon to the system via a web browser. After the users begin a search, the system dispatches agents to conduct an SIP information inquiry and collection mission. The IC designer acts as an SIP user, while an IC manufacturer or an SIP vendor acts as an SIP provider. There are four agents in the SIP user's host, including KSTP, Barracks, Marine and Statistician agents (figure 5, process A). Each agent is in charge of different stages of the SIP inquiry and collection. For the SIP provider, there are two agents–the Guard and Retriever agents. The Guard agent is in charge of verifying the Marine agent and the Retriever agent helps the Marine agent access the local database after authorization is approved (figure 5, process B). When the Retriever agent finds the SIP documents that the user requires, it delivers the SIP documents to the Marine agent. Then, the Marine goes back to the original host for reporting. Both provider and user site agents engage in collaborative actions for the mission. Further, when the Marine agents start the SIP collection task, users can login to the monitoring system (Barracks) to query the status of the agent activities and generate a report.

4.2. Agent-based SIP matching evaluation system

The agent-based SIP matching system supports the SIP buyers and sellers when they start the matching evaluation process. The goal is to suggest suitable trading partners with quantitative rankings. The agent-based SIP matching system is located at the matching broker site. There are two types of users, i.e. the general users (SIP buyers or sellers) and the brokerage administrator (i.e. the intermediator). The system consists of a registration module, the trading-data maintenance module, a membership-function maintenance module and the administrator maintenance module. The process flows, as shown in figure 6, specify the key matching processes (A sub-figure), and the drilled-down processes for maintaining the fuzzy membership functions (B sub-figure).

Buyers and sellers maintain their trading data via the trading data maintenance module. The users select the targeted SIP (for buying or selling) determine trading

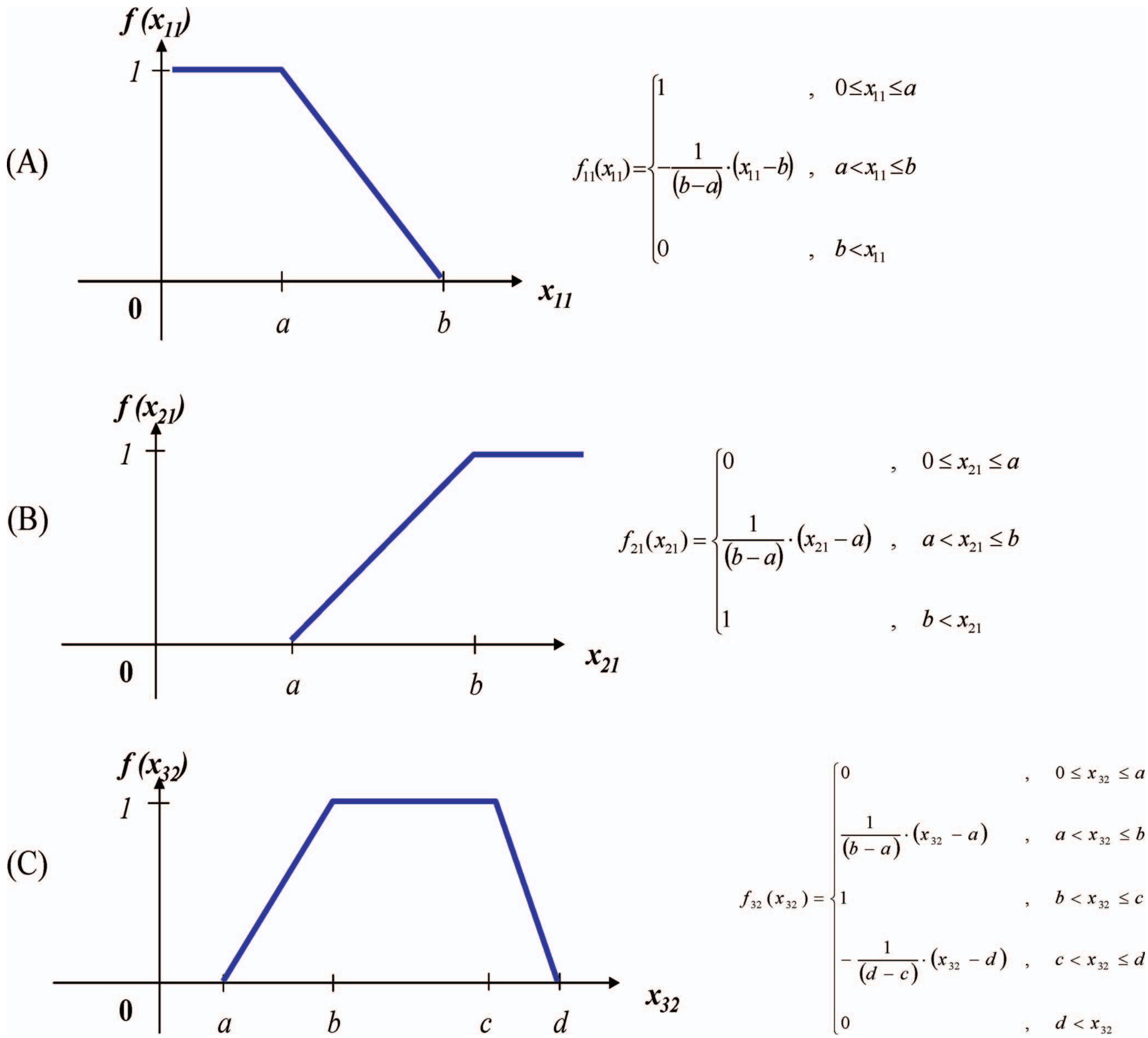

Figure 3. Three types of membership functions for the mapping of KPI values toward the preference quantifiers, *f(x..)*.

partner candidates using the matching process. The system requests the users to enter information related to the company demographics. Buyers and sellers can also create, delete, query and update the fuzzy membership functions using the membership function maintenance module. The membership functions establish the criteria for the matching decision support. When users add a new membership function, they select an index from the system which becomes the default value. There are several default membership functions in the system for users to select and modify that suit the users concerns (section 3.2). In summary, the web interfaces as shown in figure 7 can add, delete and change details of membership functions.

When the matching deadline expires, the system initiates the matching process in order to find suitable partners. A Detector agent from the matching broker's site monitors the deadline and if it is expired, it signals the Broker agent to begin matching players. The Broker agent retrieves users' data including matching data and membership functions. After confirming the players, the Broker agent starts to evaluate the data based on the matching fuzzy model. When the process is completed, the Broker provides

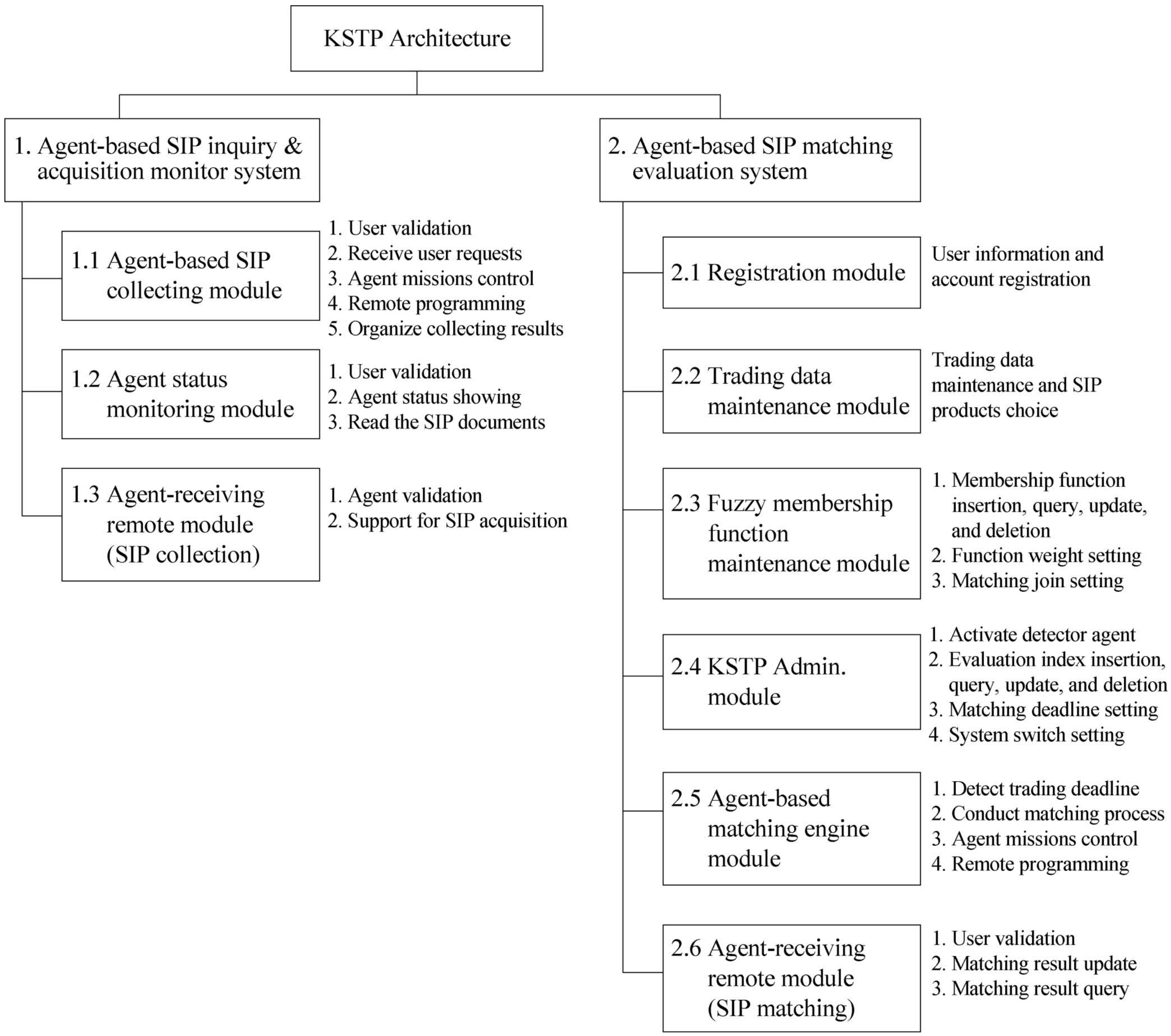

Figure 4. KSTP prototyping architecture and the detailed functional modules.

each player's suggestion list ranked by each trading partner's performance value. Then, the Broker agent passes the information to the Distributor agent used to dispatch Marine matching agents to the player's host. When the Marine matching agent arrives at the remote host, the Receiver matching agent inserts the matching results into the local database. The collaboration flow of the agents and the matching processes is shown in figure 8.

4.3. *Comparison of KSTP and the previous research*

This research compares the KSTP kernel modules and earlier research as shown in table 4. Based on the available literatures, existing research emphasizes the information technology frameworks and development of database management and electronic libraries for SIP reuse and commercialization. Nonetheless, this research focuses on developing SIP trade mechanisms using intelligent mobile agents, embedded with fuzzy decision models, for autonomous and asynchronous actions when independent and intelligent actions are needed during the SIP information inquiry, collection, and trade partner evaluation. Although SIP reuse and trade require many more intricate factors, this research is the first step toward the realization of an automated and global SIP marketplace.

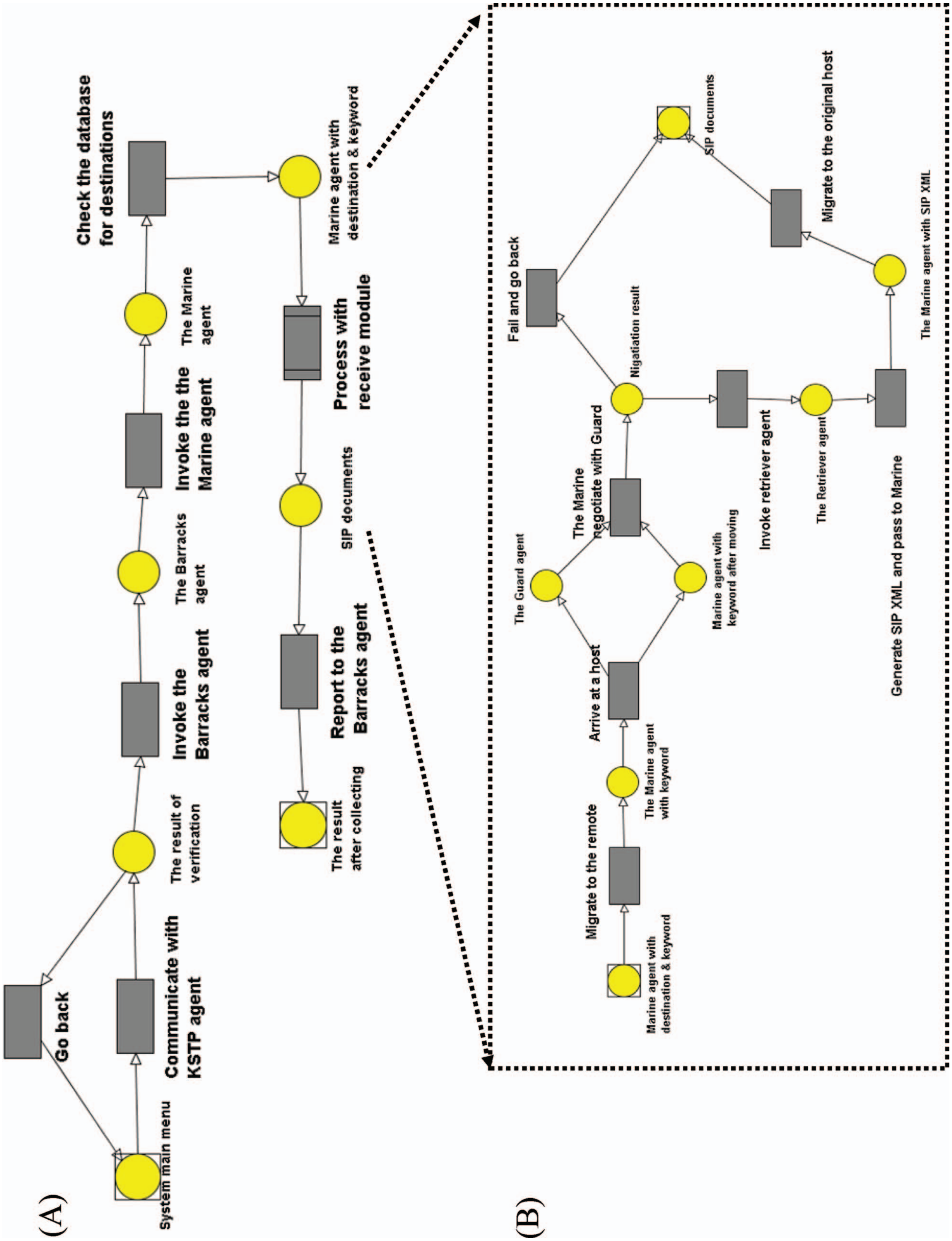

Figure 5. The SIP inquiry and collection processes with collaborative actions of four mobile agents.

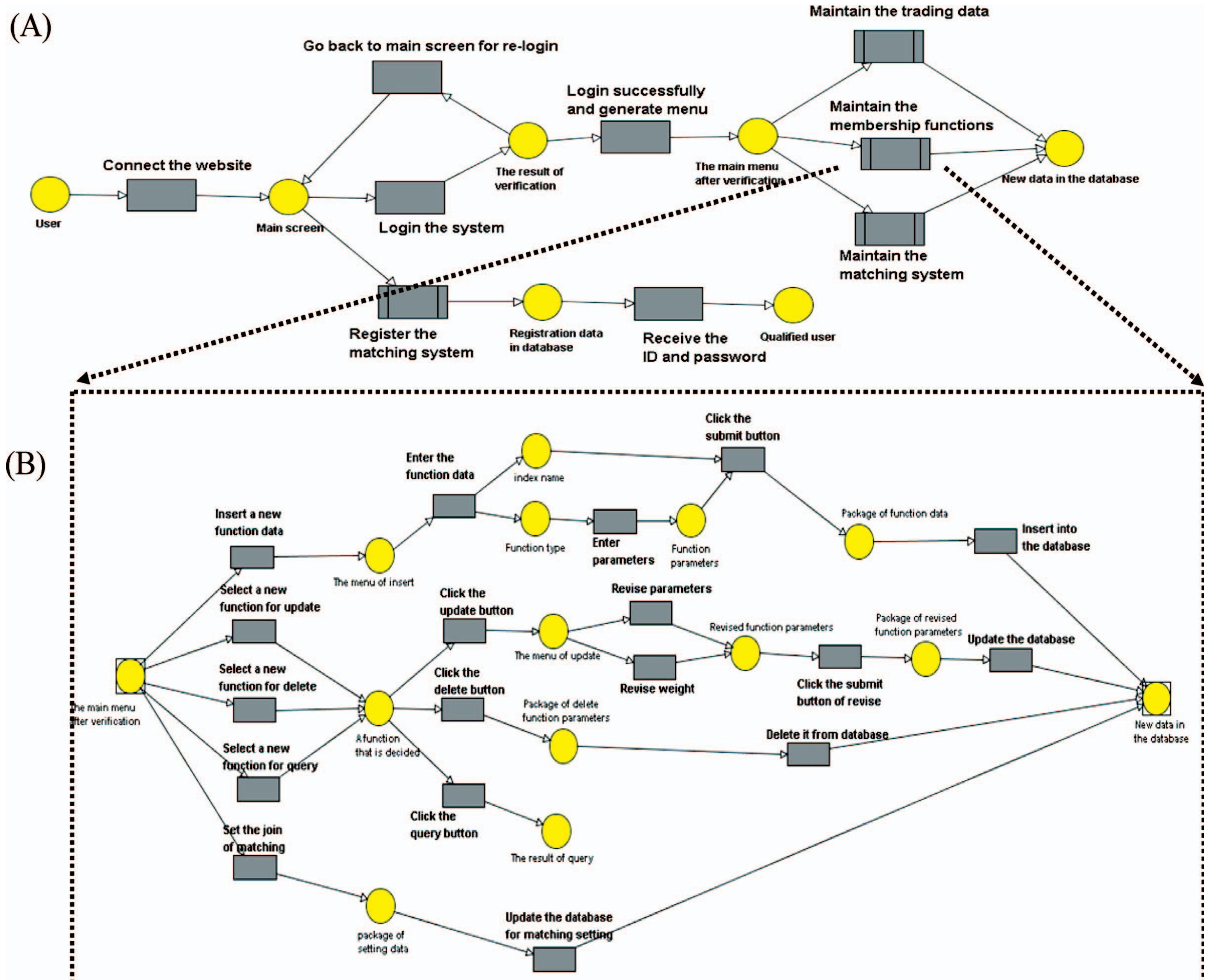

Figure 6. The process flows between the roles and modules with (a) as the main matching process and (b) as the membership management process.

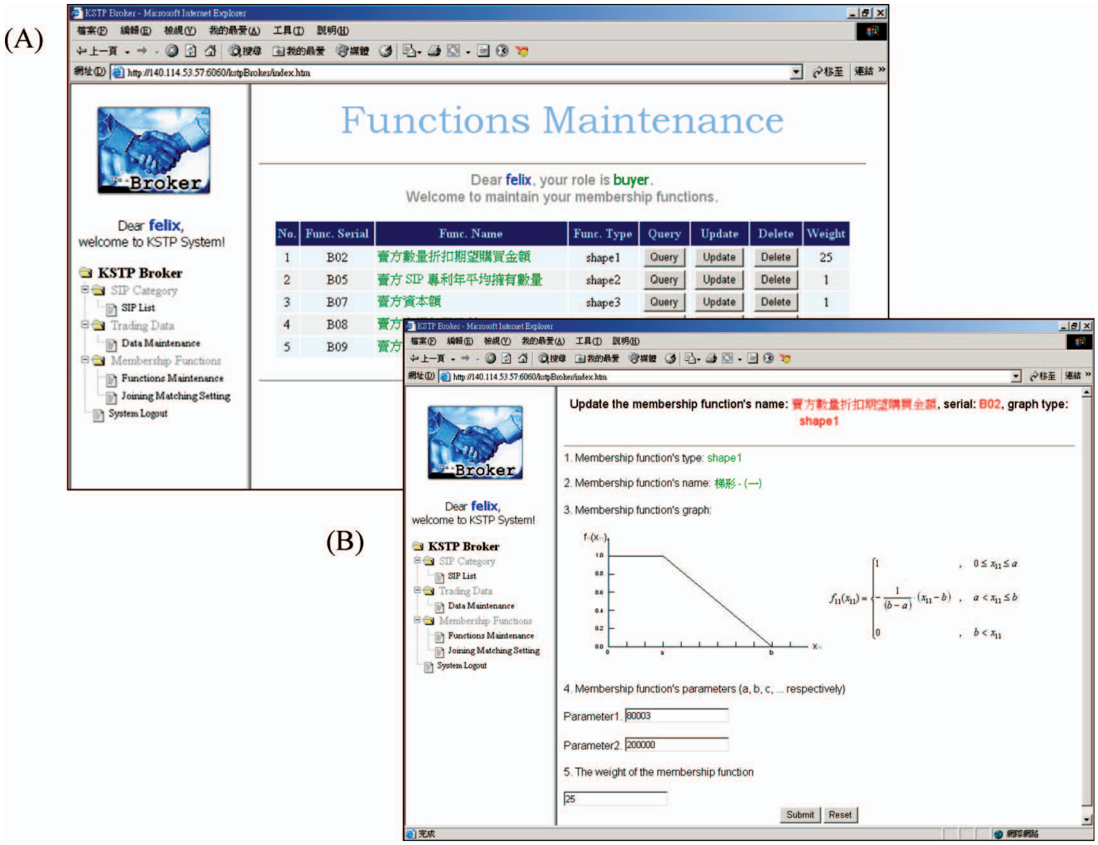

Figure 7. The web interfaces of membership function maintenance module, (a) the module entry page and (b) the parameter change page.

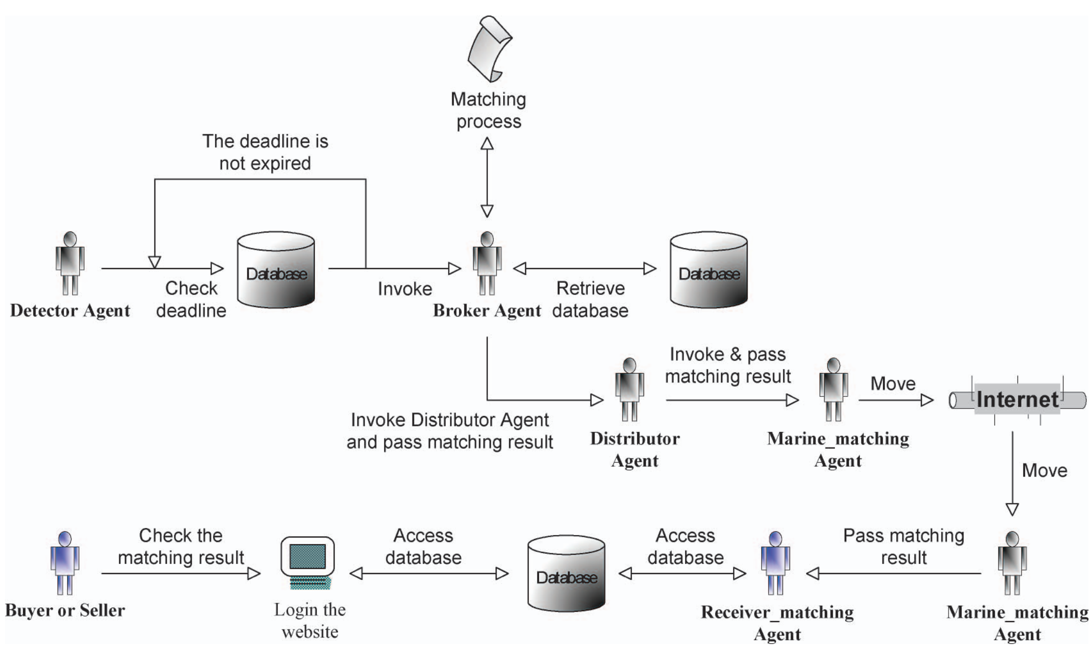

Figure 8. The collaboration of agents and the matching process (Trappey *et al.* 2006).

Table 4. Comparison of the previous research and this research.

References	Contributions
Coors *et al.* 1999	Focus on database infrastructure for distributed and heterogeneous IP reuse using CORBA mechanisms.
Lee *et al.* 1999	Design an IP database system that contains functions of IP search, IP comparison, and the download of IP.
Schindler *et al.* 1999	Develop an IP depository system that is web enabled. Provide an IP reuse infrastructure for buyers and sellers complete with searching, selecting, uploading and downloading capabilities.
Gajski *et al.* 2000	Define and analyse the essential issues and business models for SIP design and reuse.
Ghanrni *et al.* 2002	Develop an XML exchange platform that consists of SIP publishing, exchange and IP information extraction.
Trappey *et al.* 2002	Define IP trade business model and develop a prototyping IP mall covering key trade processes. Apply the e-marketplace concept in the SIP trade business model.
This research	Develop novel KSTP prototyping system incorporating mobile agent technology and fuzzy decision model, which enable asynchronous and autonomous IP information acquisition and trade partner evaluation.

5. Conclusion

SIP management and public trading are becoming very important in reducing SoC time-to-market. In this research, intelligent mobile agent technology and fuzzy evaluation methods are applied to KSTP development for SIP trades. The contribution of the research is to demonstrate agent-based SIP reuse by improving the efficiency of IP data collection and trade partner evaluation. Therefore, this research presents the mobile agent-based thinking for KSTP construction. For SIP collection, KSTP provides an asynchronous and autonomous execution for SIP information acquisition via mobile agent technology. Moreover, the approach helps users reduce the IP search cost and time, which is critical in the success of SoC/ASIC design (Hsu *et al.* 2004). For SIP trading, the research also provides a matching model to ensure consistent partner evaluation and reduce trading complexity. When there are a large number of buyers and sellers in the marketplace, the matching model becomes a critical method for partner screening. Thus, SIP providers can maintain their own management rights while allowing SIP information sharing under the KSTP environment. SIP users and providers are also equipped with rational and consistent tools for SIP partner search.

The research presents the methodology of constructing the KSTP applying mobile agent technology. However, there are still issues to research concerning SIP integration and plausible business models. The uncertainty of business practices may impede the purchase and reuse of SIP. Therefore, further research on the decision models of SIP trades and reuses under different circumstances will be required fully to automate the concept.

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