S.-H. Chen • T. Terano • R. Yamamoto (Eds.)

Agent-Based Approaches in Economic and Social Complex Systems VI

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The AESCS International Workshop 2009

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Agent-Based Social Systems

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ABSS–Agent-Based Social Systems

This series is intended to further the creation of the science of agent-based social systems, a field that is establishing itself as a transdisciplinary and cross-cultural science. The series will cover a broad spectrum of sciences, such as social systems theory, sociology, business administration, management information science, organization science, computational mathematical organization theory, economics, evolutionary economics, international political science, jurisprudence, policy science, socioinformation studies, cognitive science, artificial intelligence, complex adaptive systems theory, philosophy of science, and other related disciplines.

The series will provide a systematic study of the various new cross-cultural arenas of the human sciences. Such an approach has been successfully tried several times in the history of the modern science of humanities and systems and has helped to create such important conceptual frameworks and theories as cybernetics, synergetics, general systems theory, cognitive science, and complex adaptive systems.

We want to create a conceptual framework and design theory for socioeconomic systems of the twenty-first century in a cross-cultural and transdisciplinary context. For this purpose we plan to take an agent-based approach. Developed over the last decade, agent-based modeling is a new trend within the social sciences and is a child of the modern sciences of humanities and systems. In this series the term "agent-based" is used across a broad spectrum that includes not only the classical usage of the normative and rational agent but also an interpretive and subjective agent. We seek the antinomy of the macro and micro, subjective and rational, functional and structural, bottom-up and top-down, global and local, and structure and agency within the social sciences. Agent-based modeling includes both sides of these opposites. "Agent" is our grounding for modeling; simulation, theory, and real-world grounding are also required.

As an approach, agent-based simulation is an important tool for the new experimental fields of the social sciences; it can be used to provide explanations and decision support for real-world problems, and its theories include both conceptual and mathematical ones. A conceptual approach is vital for creating new frameworks of the worldview, and the mathematical approach is essential to clarify the logical structure of any new framework or model. Exploration of several different ways of real-world grounding is required for this approach. Other issues to be considered in the series include the systems design of this century's global and local socioeconomic systems.

Shu-Heng Chen · Takao Terano
Ryuichi Yamamoto
Editors

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Preface

Social science is moving in a direction in which its various constituent parts are sharing a common set of foundations, languages, and platforms. This commonality is making the social sciences unprecedentedly behavioral, algorithmic, and computational. At the turn of the twenty-first century, a group of computer scientists and social scientists worked together to initiate new series of conferences and to establish new academic organizations to give momentum to this emerging integration now known as computational social sciences. One of them is the International Workshop on Agent-Based Approaches in Economic and Social Complex Systems (AESCS), which originated in Japan. The first five AESCS workshops were all organized in Japan – Shimane (2001), Tokyo (2002), Kyoto (2004), and Tokyo (2005, 2007). The sixth was the first one to be held outside Japan. It was hosted by National Chengchi University in Taipei, Taiwan, and co-hosted by the Pacific-Asian Association for Agent-Based Approaches in Social System Sciences (PAAA) as its biennial conference.

On the occasion of AESCS'09 we had 39 presentations, which were delivered in single sessions on November 13 and 14, 2009. In addition to the regular presentations, three keynote speeches were given, by Jeffrey Johnson (Open University, UK), Sobei Oda (Kyoto Sangyo University, Japan), and Takao Terano (Tokyo Institute of Technology, Japan). While most of the time the "agent" in agent-based modeling refers to software agents, the increasing involvement of human agents and their interactions with software agents has given agent-based social modeling a new direction to explore, which is known as experimental agent-based modeling or participatory simulation. To feature this new development, AESCS'09 also offered a one-day tutorial on software for software-agent simulations and human-subject experiments. The tutorials included SOARS (lectures by Hiroshi Deguchi, Manabu Ichikawa, and Hideki Tanuma), Netlogo (Bin-Tzong Chih) and z-Tree (Chung-Ching Tai).

As in the previous five events, we also prepared a post-conference publication to archive selected papers as evidence of the advances in computational social sciences. Fourteen papers were selected to be included in this volume, each being reviewed by three to four referees. These 14 papers were then further grouped into six parts. Of these, Part I, "Agent-Based Financial Markets," and Part II, "Financial Forecasting and Investment," have long-standing positions in the literature.

We believe that these two topics will continue receiving attention from scholars as well as the general public, particularly after the recent financial tsunami. Part III, "Cognitive Modeling of Agents," is a new direction in agent-based social sciences. Cognitive capacity, as well as other related measures, has been studied by cognitive psychologists for decades. However, only recently has this constraint sensibly been taken into account in constructing artificial agents so as to, from a microscopic viewpoint, better mimic the human behavior observed in, for example, human-subject experiments, or, from a macroscopic viewpoint, to better understand the emergent complex phenomena. The two chapters included in this part are examples of this kind of work.

Agent-based models of complex adaptive systems obviously provide an alternative way of thinking about policy making in a complex and uncertain environment. The flexibility of agent-based models provides us with tremendous opportunities for policy simulation under various scenarios, from the behavior of stakeholders and interaction networking to environmental uncertainties. This information regarding the landscape of outcomes can be particularly useful in evaluating the potential risk of policy regimes. The three chapters included in Part IV, "Complexity and Policy Analysis," address policies related to pension funds, local taxes, and marketing.

Needless to say, all great challenges currently facing primates and human societies are interdisciplinary. The solutions require not just technology, but also fence crossing among the various social sciences. Agent-based modeling as an integration platform within the social sciences is becoming active in tackling these challenges. Part V, "Agent-Based Modeling of Good Societies," is an example of this development. The three chapters included in this part use agent-based modeling to address the issues of human well-being: peace, greenness, and disaster management, respectively. The remaining two chapters are included in Part VI "Miscellany," which extends the volume to applications to organizations and management and a literature review of the computational social sciences.

We do hope that this volume (AESCS'09), as a continuation of the past decade and the opening of a new decade, can stimulate and motivate more prospective readers, particularly young scholars, to join this growing and exciting area and contribute to the flourishing development of the computational social sciences.

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Part I
Agent-Based Financial Markets

Comprehensive Analysis of Information Transmission Among Agents: Similarity and Heterogeneity of Collective Behavior

Aki-Hiro Sato

Abstract Recent development of Information and Communication Technology enables us to collect and store data on human activities both circumstantially and comprehensively. In such circumstances it is necessary to consider trade-off between personal privacy and public utility. In the present article I discuss methods to quantify comprehensive states of human activities without private information and propose a measure to characterize global states of societies from a holistic point of view based on an information-theoretic methodology. By means of the proposed method I investigate participants' states of the foreign exchange market during the period of the recent financial crisis which started around the middle of 2008. The results show that drastic changes of market states frequently occurred at the foreign exchange market during the period of global financial crisis starting from 2008.

Keywords Bipartite graph · Degree centrality · Shannon entropies · Kullback–Leibler divergence · Jensen–Shannon divergence · Foreign exchange market

1 Introduction

Recent development of Information and Communication Technology (ICT) enables us to communicate with one another via electronic devices and a ubiquitous environment has been realized everywhere from commerce to education. One can further collect and accumulate large amounts of socio-economic data on human activities, and analyze and visualize them in principle. Based on vast amounts of data from socio-economic systems new types of commercial services and research fields have been emerging. Specifically, several researchers in the fields of sociology, economics, informatics, and physics are focusing on these frontiers and have launched data-oriented sciences in order to understand the collective behavior of human groups [1–11].

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However, since our society, which is the sum total of both internal and external states of individuals, is several orders of magnitude more complicated than each individual, it seems to be impossible for us to capture its real total states even if several humans cooperate to capture them. In other words the “complexity” of our society leads to and/or comes from our nescience.

Therefore it is required that we may develop methodologies to compress or extract information from vast amounts of data on the states in our society with higher degrees of freedom than each individual’s degrees of freedom. If technological advances make such unobservable circumstances perceptible then they may provide us with predictability and manageability for our society. We further may be able to find arbitrary opportunities obscured due to the nescience and improve several undesirable circumstances.

According to Heinz von Foerster [12] complexity is not of any properties which observed systems possess but it is to be perceived by observing systems. He asks us about it through the following question: *Are the states of order and disorder states of affairs that have been discovered, or are these states of affairs that are invented*? If the states of order and disorder are discovered then complexity means the property of the observed systems. If invented then it is perceived by the observing systems.

In this article, following Foerster’s definition of the complexity, we suppose that the degree of order and disorder is relatively determined by the degrees of freedom of an observed system and an observing system. One of the most dominant reasons why we recognize the complexity in observed systems is because finiteness of periods when and abilities where we are able to observe the systems and limitations of our memory and a priori knowledge on them lead to our bounded rationality or nescience. Therefore, if we can overcome nescience with comprehensive data on the observed systems by means of massive computation then we will be able to make complexity change to simplicity. Moreover, if we can invent the definition of the states of order and disorder then we have an ability to perceive the states of order and disorder. Therefore it is important for us to have a conceptual framework for coping with complexity in human societies.

Our own knowledge is a part of *the whole of knowledge*, and *the whole of knowledge* consists of each part of our own knowledge. Therefore it seems to be impossible for us to comprehend the whole of knowledge because of our finiteness. However it is possible for us to know it by intuition. This intuition for *the whole of knowledge* is a “comprehensive” perspective which is expected to lead us to a holistic point of view.

The aim of the present article is to propose methods to quantify and visualize attentions of participants in groups whilst protecting the anonymity of agents from a holistic point of view. Specifically I focus on the foreign exchange market and attempt to comprehensively visualize market states of the foreign exchange market with high-resolution data recorded in an electronic brokerage system.

The rest of this paper is organized as follows. In Sect. 2 a literature survey is carried out through recent studies on data-centric socio-economic sciences. In Sect. 3 I propose an agent-based model of a society consisting of N kinds of groups where M participants exchange contexts, and propose methods to capture states of participants in a practical manner. In Sect. 4 I show results of empirical analysis on states of the foreign exchange market by means of the proposed methods with high-resolution data. Section 5 is devoted to conclusions and used to address future works.

2 Literature Survey

Recently several researchers in a wide spectrum of fields have paid a remarkable amount of attention to massive amounts of comprehensive data. For example, search engines of Web services need massive data about hyperlink connections among Web pages, and electronic commerce systems need to cover various kinds of products. Due to the development of ICT, the Advanced Information Society has already emerged globally and it has eventually made our world to be smaller and smaller. For such circumstances the concept of information explosion has been proposed [13, 14]. This concept is that the total amount of information created by individuals exceeds the individuals' information processing capability. According to recent studies on the information explosion, it is predicted that the total amount of information created by human beings will reach over 1Zbyte/year around 2010.

Studies based on vast amounts of socio-economic data have several branches. Here five kinds of recent studies (financial market data, demographic data, traffic flow data, POS data, and Web-commerce data) are surveyed for the purpose of finding directions to cope with the complexity of human societies.

A large amount of data on financial markets is available because the electronic matching systems of financial markets are spreading all over the world due to the development of ICT. Recent trading is done through electronic platforms and settlement operation is done through electronic clearing systems. Financial market data can be collected through a direct API or through the historical data centers of data providers. Applications of statistical mechanics to finance by means of statistical physics, agent-based modeling and network analysis have progressed during the last decade [1–4].

The launch of E-Stat database by the Japanese government [5] provides us with new technology for data-based understanding of our country. Specifically, based on demographic data everyone can understand the state of our country from a viewpoint of population in principle. Furthermore, real-time demographic data are also available since the technologies to collect human activities via each personal mobile phone have been established [6]. In the near future we will be able to visualize real-time demographics both comprehensively and circumstantially.

Recently, several car navigation companies have launched autonomous sensory navigation services in Japan. As a result, these companies can collect real-time car traffic data via each car navigation terminal. Moreover, by collecting data from many cars one can find roads and points where traffic jams are occurring. Without constructing new infrastructure to collect traffic states they can accumulate real-time traffic data due to the development of Integrated Transport Systems (ITS). Based on such data comprehensive analysis of traffic flows can be conducted in order to cope with traffic jams [7]. Recent developments of traffic measurement technologies have been driving the theoretical development of traffic control and modeling [8].

POS is an abbreviation for "point-of-sales" and all the department stores and supermarkets have introduced this kind of system in order to ring up the amounts at the cash registers. As a result, retail sales can be managed in real-time and data centric operations can be done. On the basis of massive amounts of data, marketing methods have been developed. The statistical properties of expenditure in a single shopping trip show a power-law distribution [9]. A comprehensive analysis of retail sales is one of the prominent directions to be followed in order to bridge between microeconomics and macroeconomics.

Web-based commerce systems enable us to purchase everything from books to electronic equipment, via web sites. The details of consumers and goods can be stored on the data-base engine of each web site. If we can use such data, then we may, in principle, capture real-time demand and supply of all the items which are traded via web sites. Analyzing massive amounts of data on items which are sold via web commerce systems is expected to open a window to new economic theory and service engineering [10, 11].

The common properties of these studies seem to overcome the complexity in socio-economic systems by using massive amounts of data and vast computations. Copious amounts of data on human activities are collected by means of ICT and vast amounts of computation for such data are conducted for the purposes of searching, matching, visualizing and extracting.

Specifically in the literature of Cloud Computing, users practically use their service provider's computers via a rich network infrastructure and store their data on the provider's storage. Therefore, in principle, it is possible for us to integrate collected personal data and to even understand the states of order and disorder of the affairs based on vast amounts of data and of computation.

On the other hand, in such circumstances we have to consider the trade-off between personal privacy and public utility. In this context almost all advanced countries have Private Information Protection Laws. Hence, protection of personal privacy is one of most important issues involved in dealing with personal data in Cloud Computing. If it is permitted for us to secondarily use such data, then it can be a useful infrastructure for us to capture our society and to circulate our knowledge from a comprehensive point of view. In the following sections we consider a method of capturing the global states of affairs whilst protecting personal information.

3 Model and Methods

In this section I discuss methodologies to quantify the total states of affairs created by participants' activities and discriminate them for different observation periods from a comprehensive point of view. Specifically methods to characterize an indicative index with data from all the components of which the system consist.

The fundamental ideas are to focus on relative frequencies within group activities, and to quantify and to discriminate patterns based on their relative frequencies. Since the relative frequencies of group activities are quantities which can be computed from the number of activities for an observation period it is possible to count the actions of agents without any knowledge of private information. By repeatedly quantifying the total states of human society for each observation period we will be able to capture changes of circumstances.

According to the definition of information by Gregory Bateson [15] information is defined as *a difference which makes a difference*. In other words information is an ideal element (=meaning) of which a message changes a receiver's state. It is known that Bateson's definition characterizes information from qualitative aspects as compared with Shannon's quantitative definition of information. Moreover it is possible that agents create messages based on their inner state and receive messages from other agents in multi-agent systems. In such systems the production of messages and state variations are repeatedly done. The structure and dynamics of chaining perceptions and actions through communication among agents seem to be related to the stability of societies.

Consider N groups consisting of M agents as shown in Fig. 1. In the context of web commerce systems, agents correspond to consumers and groups correspond to goods or shops. In the context of financial markets agents correspond to traders, and groups are the commodities which are traded by agents. In the context of blog systems agents are bloggers, and groups are contents or communities. If one knows the relative activities of agents on each group then one can know the shares of those groups in society. Though the complete structure of human society is unknown and

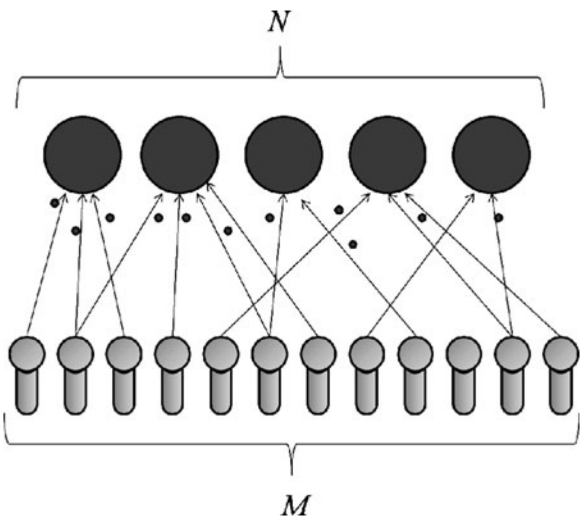

Fig. 1 A conceptual illustration of human society consisting of ***N*** groups where ***M*** agents exchange messages

unobservable, the shares of groups are computable from observations. Such kinds of activity data can be comprehensively collected by observing the arrivals of submissions on host computers.

Let $f_i(T)$ $(i = 1, \ldots, N)$ be the number of observations for the actions of agents in the ith group for the observation period $T : [T\Delta, (T+1)\Delta)(\Delta > 0)$. Then a relative frequency of the ith group's activities can be estimated as

$$p_i(T) = \frac{f_i(T)}{\sum_{i=1}^{N} f_i(T)}. \tag{1}$$

Namely, the relative frequency $p_i(T)$ may approximate the degree of centrality c_i during an observation period T [16]. On the other hand, suppose that random walkers hop from one node to another node with the same probability on a network having an adjacency matrix C_{ij}. Then a stationary residence probability of random walkers at the ith node is equivalent to the ith node's degree of centrality which is defined as

$$c_i = \frac{\sum_{j=1}^{N} C_{ij}}{\sum_{i=1}^{N}\sum_{j=1}^{N} C_{ij}}. \tag{2}$$

Recently Wilhelm and Hollunder proposed a method to characterize directed weighted networks with several nodes [17]. They consider the normalized weight of the flux between two nodes as the probability for a symbol in the transmitter signal corresponds to the sum of all influxes to/effluxes from a given node. They also propose information-theoretic measures for the normalized weight in order to characterize the shape of networks. In the case of undirected unweighted networks, the normalized weight is equivalent to the degree of centrality as shown in (2).

Since a relative frequency of actions during an observation period T may approximate to a probability for agents to be in a group, its information entropy during the observation period and the information divergence between two observation periods may characterize the state of the system at the period and quantify a distance between two states of the system. If we employ Shannon entropy as information entropy and Kullback–Leibler divergence as divergence then we can describe them as

$$S(T) = -\sum_{i=1}^{N} p_i(T) \log(p_i(T)) \tag{3}$$

$$KL(T_1, T_2) = \sum_{i=1}^{N} p_i(T_1) \log \frac{p_i(T_1)}{p_i(T_2)} \tag{4}$$

Obviously one has $0 \leq S(T) \leq \log N$, and $S(T) = \log N$ when $p_i(T) = 1/N$. Further, one has that $KL(T_1, T_2) \geq 0$ is satisfied and $KL(T_1, T_2) = 0$ if and only if

$p_i(T_1) = p_i(T_2)$ for any-i. In this definition the Shannon entropy is regarded as a special case of the Kullback–Leibler divergence. When we put $p_i(T_0) = 1/N$, we have $KL(T, T_0) = \log N - S(T)$. Namely the Shannon entropy is equivalent to the Kullback–Leibler divergence between the activity state on the network at T and uniform activity state on an undirected fully-connected network.

Furthermore in order to compare the shapes of probability distribution we can choose a divergence from f-divergence, Kullback–Leibler divergence, Jensen–Shannon divergence, and so on [18]. In the case of the f-divergence the similarity of centralities between two observation periods is defined as follow.

Let $f(u)$ be a convex function satisfying $f(1) = 0$. Then the similarity between group states on the T_1-th observation period and those on the T_2-th observation period is defined as

$$D_f(T_1, T_2) = \sum_{i=1}^{N} p_i(T_1) f\left(\frac{p_i(T_2)}{p_i(T_1)}\right) \tag{5}$$

As an alternative divergence the Jensen–Shannon divergence [18] can be adopted.

$$JS(T_1, T_2) = -\sum_{i=1}^{N} \frac{p_i(T_1) + p_i(T_2)}{2} \log \frac{p_i(T_1) + p_i(T_2)}{2} - \frac{1}{2} \sum_{k=1}^{2} S(T_k) \tag{6}$$

One has $JS(T_1, T_2) \geq 0$ and $JS(T_1, T_2) = 0$ if and only if $p_i(T_1) = p_i(T_2)$ for any i.

4 Empirical Analysis

In this section I show results of empirical analysis by means of the proposed methods with high resolution data of the foreign exchange market. The analysis is conducted by using high-resolution data collected by ICAP EBS platform (ICAP EBS Data Mine Level 1.0) [19]. In the exchangeable currency pairs consisting of 24 currencies and five precious metals,[1] 47 kinds of currencies pairs[2] are included in

[1] USD (United States Dollar), CHF (Swiss francs) EUR (Euro), JPY (Japanese Yen), NZD (New Zealand Dollar), AUD (Australia Dollar), GBP (British Sterling) CAD (Canadian Dollar), SEK (Swedish Krona), SGD (Singapore Dollar), HKD (Hong Kong Dollar), NOK (Norwegian Krone), ZAR (South African Rand), MXN (Mexico Peso), DKK (Danish Krone), CZK (Czech Koruna), PLN (Poland New Zloty), HUF (Hungarian Forint), ISK (Iceland Krone), RUB (Russian Rouble) SKK (Slovakia Koruna), TRY (Turkey Lira), THB (Thailand Baht), RON (Romanian Leu), BKT (Basket Currency of USD and EUR), ILS (Israeli Shekel), XAU (Gold), XAG (Silver), XPD (Palladium), XPT (Platinum), and SAU (Small amount of Gold).

[2] The data include records of BID/OFFER for USD/CHF, EUR/USD, USD/JPY, EUR/JPY, EUR/CHF, NZD/USD, AUD/USD, GBP/USD, USD/CAD, AUD/NZD, EUR/GBP, XAU/USD, XAG/USD, EUR/SEK, CHF/JPY, XPD/USD, XPT/USD, USD/SGD, USD/HKD, EUR/NOK, USD/ZAR, USD/MXN, EUR/DKK, EUR/CZK, EUR/PLN, EUR/HUF, EUR/ISK, USD/RUB, GBP/JPY, EUR/SKK, USD/PLN, GBP/CHF, AUD/JPY, USD/TRY, USD/THB, NZD/JPY, CAD/JPY, ZAR/JPY, EUR/ZAR, EUR/RUB, EUR/CAD, GBP/AUD, USD/SEK, EUR/AUD, EUR/RON, BKT/RUB, and USD/NOK.

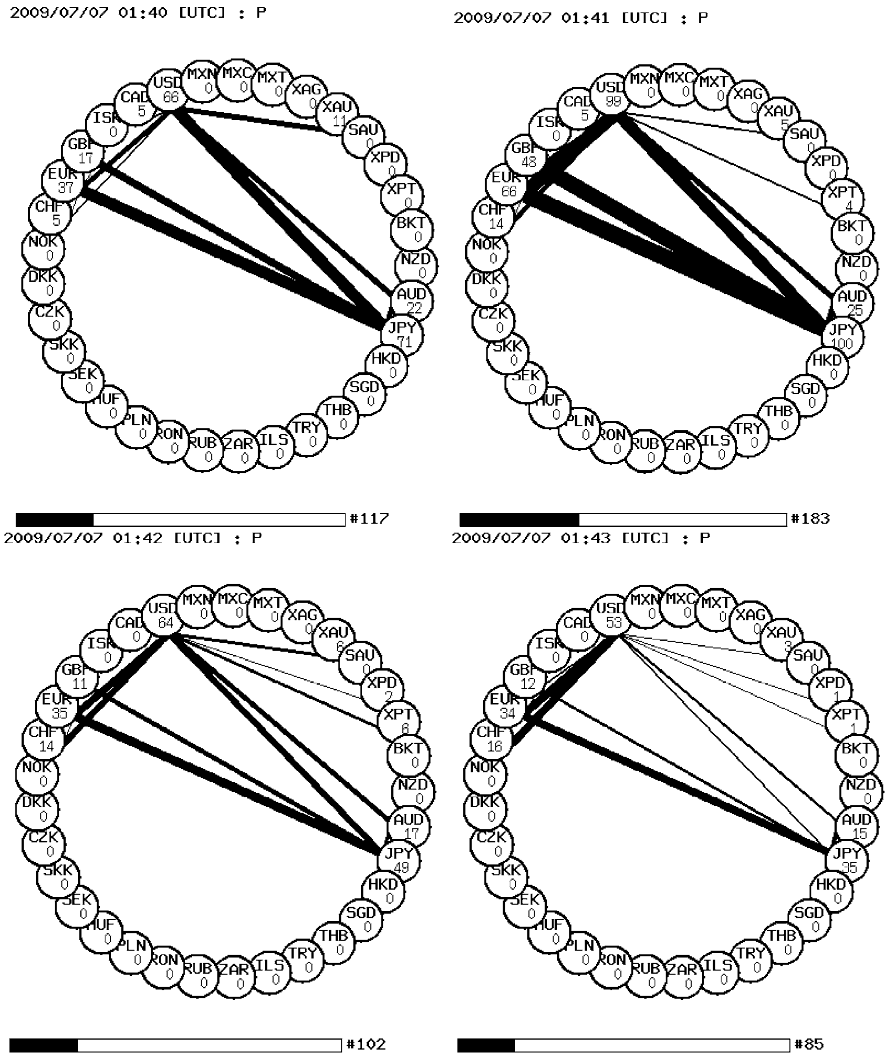

Fig. 2 Network illustrations of the number of quotation activities from 1:40 to 1:44 (UTC) on 7th July 2009. A node (the number in each node shows the number of quotations/transactions) represents currency and a weighted link represents the flow of each currency pair

the data set with 1-s resolution during a period from June 2008 to December 2009.[3] Figure 2 shows weighted network illustration visualizing the number of quotations for each currency pair within 1-min over the whole market. Nodes represent currencies, and weighted links between two kinds of currencies the number of quotations (left) and transactions (right). It is found that the activities of quotations temporally

[3] Totally 123,958,633 records are found in the dataset.