



# A literature review on the space of flows

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## Abstract

With the support of information and communication technologies (ICTs), production elements are flowing and interacting with each other continuously. Human production and living activities are no longer confined to the traditional space (space of places, SoPs), but extended to a new kind of space (space of flows, SoFs). With its liquidity, SoFs can greatly break through the limitation of time and space. By means of the flow and interaction of all the element flows, SoFs has been aggressively expanded to the whole field of human activities, and is guiding the formation and development of the regional space to a large extent. This paper aims at conducting a more comprehensive understanding of SoFs. Our research mainly includes the following correlative contents: (1) studying the formation and development of the concept of SoFs, and the association between SoFs and SoPs; (2) analysing the theory of SoFs and its interaction mechanism: (a) revealing the embodiment of the three elements of space in SoFs; (b) analysing the definitions and functions of material flow, population flow, information flow and capital flow, and their relationships; (c) focusing on the information guidance mechanism for the formation and development of SoFs; (d) analysing the interaction mechanism among entities in SoFs by introducing the labor division theory, interdependence theory, and competitive cooperation theory. The main conclusions can be drawn as follows: (1) SoFs depends on and goes beyond SoPs. They will coexist for a long time. (2) In SoFs, all participants have their own “positions” or “locations.” Meanwhile, there are “distances” among different participants. The flow of the element flows in SoFs is caused by demands, attractions or other external forces. (3) All kinds of element flows in SoFs interweave and influence each other. By this way, they promote the development and evolution of SoFs. Any element is indispensable, while the information flow is at the core position and plays a guiding role in the formation and development of SoFs.

**Keywords** Space of flows · Space of places · Element flows · Information flow

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## Introduction

Space is a polysemantic term. Researchers may have different opinions on the concept of space from different perspectives, such as living space, production space, and cyberspace.

From the perspective of geography research, space can be understood as a range. Geographical space is referred to the physical space existing objectively on the earth's surface. Reference Chen et al. (2001) thinks that geographical space is a distribution pattern of material, energy, and information in form, function, and structural process. It goes up to the ionosphere of the atmosphere and down to the Moho discontinuity of the mantle. The study of geographical space has become one of the basic cores of geography. Its research contents mainly include two aspects. One is research on geographical space itself, while the other is that on the geographical objects existing in geographical space. For the former, the research work can mainly be classified into the following three categories: (a) the macro-differentiation and micro-variation characteristics

of geographic space; (b) the economic value of geographic space optimization and location selection; (c) the redistribution of material, energy, and information in geographic space. For the latter, the research work can be carried on from the following aspects: (a) the distribution forms and patterns of geographical objects in the space; (b) the spatial behaviors of geographical objects, the characteristics of spatial effects, and the coupling of spatial features and time elements; (c) the principles and rules of spatial filling of geographical objects; (d) the characteristics of geographical objects interacting with each other in the space; (e) the basic relationships among geographical objects in the space, and the influence of distance factors on the relationships. In the view of reference Guo et al. (2006), geographical space is a definition or division of the region where geographical phenomena occur, or a geometric space with geographical location. In Geographic Information System (GIS), geographical space can be described by a set of discrete objects or fields with attributes (such as location, range, and shape). These objects or fields are interconnected by spatial relationships such as intersection or interconnection.

Under the influence of information technologies (ITs), the traditional concepts of time and space are being redefined. ITs have brought fundamental changes to the space-centered geography (Zhen and Gu 2002). Now, the organizational model of regional space is largely determined by the dynamic interaction between the traditional geographic space (space of places, SoPs) and the elements (such as population flow, material flow, information flow, and capital flow) in space of flows (SoFs). ITs have not only profoundly affected human social system and economic structure but also reconstructed the structure of global physical space (real space) and virtual space. During the process of urban operation, the administrative boundaries are increasingly blurred, while the spatial relationships among cities and regions are becoming more and more complex and networked. The need to handle human activities and interactions in both physical and virtual spaces introduces a major challenge to the GIScience research community. To facilitate the research work on human dynamics, Shaw and Sui (2018) proposed a multi-space GIScience framework. In this framework, they proposed the concept of relative space, relational space, mental space, and absolute space, which are relevant to different aspects of human activities and interactions in the modern world. Furthermore, they Shaw and Sui (2020) critically examine the concepts of space and place in geography in general and in geographic information science (GIScience) in particular. By engaging research on smart technologies with geography and GIScience, they seek to move beyond the crude, and often simplistic, conceptualizations of space and place by synthesizing the multiple dimensions of both space

and place. Their work can help us understand human dynamics better from a synergistic perspective of both space and place.

The form of regional space has evolved from SoPs to a new type of space with coexistence of SoPs and SoFs. The concrete manifestations of the coexistence are shown as follows: (1) SoPs is expanding to the adjacent space or the relational space; (2) the influence of SoFs on the organization pattern of regional space is deepening. It is constantly impacting and even beginning to replace the traditional space (SoPs) in some fields. (3) SoFs breaks through the limitation of time and space, and guides the formation and development of the future regional spatial pattern to a certain extent. It is extending to all areas of human activities with the aid of the interactions among element flows. The construction and development of SoFs has its own characteristics. At present, we are living not only in the real space constructed by reinforced concrete but also in the “soft city” constructed by digital communication network. Constructing and combing the theories about SoFs can help us solve the following problems: (1) making the flow among regions move from disorder to order, and from inefficient to efficient; (2) providing solutions to solve the problems of the influx of population, materials, capital, and information on urban, which is a relatively fixed space bearer; (3) benefiting the urban spatial planning by putting forward some paradigms for the development of SoFs in combination with the development of ITs.

To better understand SoFs, it is necessary to make clear the following relevant problems: 1) What is SoFs and how its concept comes into being? (2) What are the constitute elements of SoFs? (3) What are the differences, similarities, and relationship between SoFs and SoPs? (4) What is the principle of the interactions among entities in SoFs? (5) What are the main aspects in the research on SoFs? For this propose, we carry out our work according to the research ideas and plans shown in the figure below (Fig. 1).

As shown in Fig. 1, the main work in this paper includes the following: (1) elaborating the concepts of SoFs; (2) exploring the constitute elements of SoFs and their relationships; (3) analyzing the correlation and comparison between SoFs and SoPs; (4) studying the interaction mechanism of SoFs; (5) introducing relevant researches on other aspects of SoFs. When carrying out these work, we pay more attention to the following aspects: (1) the functions, definitions, and correlations of the core constitute elements (information flow, population flow, capital flow, and material flow); (2) the information guidance mechanism for the formation and development of SoFs; (3) bringing some relevant theories to explain and describe the interaction mechanism of SoFs.

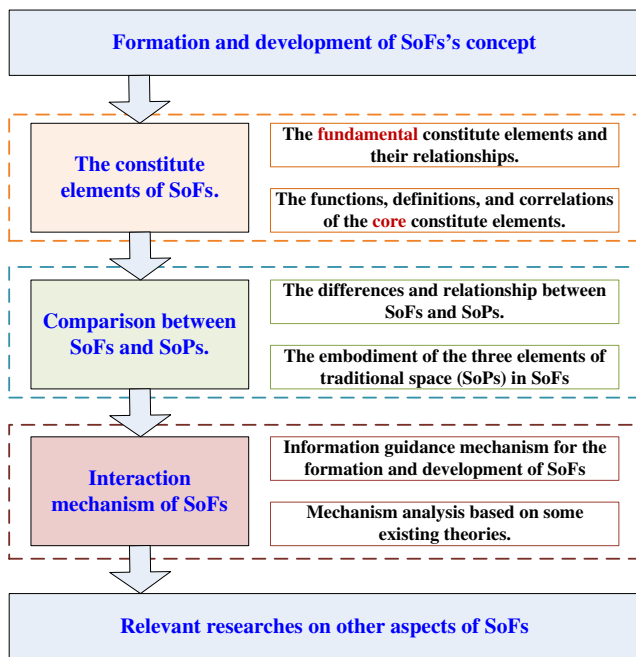


Fig. 1 Research contents and structure

### Formation and development of SoFs's concepts

It is generally believed that the real space is a region with a specific location and scope. There are certain differences in one or some aspects among different regions. But in the information age, new changes have taken place in time, space, and their relationships (Kellerman 2000). Researchers have divided the space from different perspectives. Some representative divisions are shown in the following table (Table 1).

Further, the specific contrasts among virtual space, real space, and grey space are shown in the table below (Table 2).

With the continuous development of ITs, the erosion and impact of virtual space on real space is increasing, so that some scholars have made some extreme assertions, such as “the effect of distance in the traditional sense will no longer exist, and ‘city’ will disappear.” But as mentioned in Table 2, even though some functions of real space may be gradually replaced, and some activities can be transferred to virtual space, the real matters in real space cannot be replaced.

Virtual space can be seen as constituted by various kinds of flows and their flows. From this point of view, it is similar with SoFs. From the perspective of spatial morphology, SoFs is a form of grey space. It lies between real space and virtual space, which making it not only own the geographical properties of real space (relying on physical places, information infrastructures and other

carriers) but also have the virtuality of virtual space. From the perspective of manifestation, flow-ability is one of the important characteristics of SoFs. Various kinds of element flows in the space are constantly flowing, thus bring the constantly evolution and development of SoFs.

With the support of ICTs, essential productive factors are constantly flowing and influencing each other. Human production and living activities are no longer confined to SoPs but extended to SoFs.

Castells first proposed the concept of SoFs. Since then, he has kept updating its concept (Castells 1985). In Castells (1989), he argued that the carrier of complex geographic processes can be described by “Space of Flows.” The so-called SoFs can be referred to a kind of basic spatial structure based on information and communication infrastructure, and dealing with large-scale economic information activities. In this space, information network is the core factor that determines the relationships among organizations. At this time, the concept of SoFs already has the meaning of geography and sociology. After that, he further described SoFs as “the space of flows is the material organization of time-sharing social practices that work through flows” (Castells 1992, 2010).

SoFs has attracted the attention of many scholars. They try to explain its formation, composition, and concept under different historical and geographical backgrounds.

Smith (1996) endorsed the contribution and importance of Castells’s “space of flows” proposition. However, he held different views on some of Castells’s views, and dialectically combined with specific counter-examples, and then supplemented and revised Castells’s views. He claimed that we should not blind us to the continued importance of fixed spaces and place. It is not so much that place is deracinated in the space of flows than that the relationship between the fluidity and fixity of space is itself restructured-often in surprising ways, and certainly not in a unidirectional manner. Appadurai put forward five main types of SoFs under the framework of SoFs: technological landscape, financial landscape, national landscape, media landscape, and ideology (Appadurai 1997). Himanen argued that SoFs conquers the logical experience of SoPs both by connecting two previously isolated or far apart areas with common functions and meanings and by virtue of electronic circuits and fast transit corridors (Himanen 2001). Abdelfattah studied the impact of Castells’s SoFs and Betty’s “cyberspace” on current urban and urban space (Abdelfattah 2002). Zook took the Internet industry as an example to explore the ways in which e-commerce and geographic information interact (Zook 2003). He noted that digital products, low thresholds, cost variances, and sensitivity to regulation have created a global model, a common and complex geographic environment for site administrators and consumers. The roles of individuals in

**Table 1** Several representative spatial partitioning methods

Researcher	Partitions	Definition/explanation
Flusser (1991)	Living Space	It is a Newtonian space and a topological thinking space.
	Einstein's Relative Space	A world that continues to accelerate at a speed of light. It is also a global relative space.
Thackara (1995)	Planck's Space	A quantum space that accompanies with information revolution.
	Architectural Space	It is a stable, reliable and basic space. Architects and planners can master the display of large view through it.
	Flying Space	The global level of aviation, the firmament, electronic symbols and people's interaction space
Castells (1996)	Information Space	The space of electronic communication, thought, etc.
	Space of Flows (SoFs)	Castells argues that SoFs consists of three layers: 1) The first layer is made up of electronic pulse circuits (microelectronics, telecommunications, computer processing, broadcasting systems, etc.). It has created a non localized and free society. 2) The second layer is composed of nodes and hubs, which make the network connect the specific places with clear social, cultural, material and functional characteristics. 3) The third layer is the dominant spatial organization of the management elites, which promotes an asymmetrical organized society.
Zhen (2004)	Space of Places (SoPs)	It is an actual space, a real space.
	Real Space	Material carriers of various social and economic activities in real life. It consists of social and economic activities (such as cities, residential areas, industrial belts, independent industrial and mining sites) and natural landscapes (such as rivers and mountains).
	Virtual Space	It is an anthropomorphic space that evolved from pure technological space.
	Grey Space	The only way for real space to move towards virtual space. It is a transitional space formed by the interaction and fusion of real space and virtual space.

**Table 2** Comparisons among real space, virtual space, and grey space

Name	Important attributes	Explanation
Real space	(1) Materiality (real existence), centrality (not homogeneous), and boundaries. (2) Five key points: distance, accessibility, agglomeration, different scale and relative position.	Although real space is constantly eroded and influenced by virtual space, even though its function may be gradually replaced, the real material in it cannot be replaced.
Virtual space	(1) It has infinite transcendental and strong penetrability in space; it shows virtuality, fluidity, uncertainty, jumping and spreading in form; it has openness, variety, interaction and timeliness in function. (2) There are essentially no centers. Although it has no centers itself, its combination with real space follows or strengthens the original centers. Those centers that are temporarily excluded from virtual space may decline or even disappear.	(1) Western scholars try to describe the space with cyberspace, information space, and digital space. (2) Reference Zhen (2004) defines virtual space as a new type of space supported by information technology, space technology and corresponding organizations.
Grey space	Consisting of material sites, computers or mobile devices that can be connected to the Internet, and network facilities. Variability and timeliness.	(1) Reference Bakis and Zi (2000) call it geo-cyberspace. (2) According to access mode, it can be divided into fixed types and mobile types; According to the purpose of access, it can be divided into entertainment, knowledge, industry and management; In terms of space, it can be divided into buildings, communities and urban grey space.

the Internet industry are largely influenced by the historical and economic conditions of their residences rather than simply determined by the logic of cyberspace interaction. Therefore, he believed that if we want to understand SoFs better, we must refer to SoPs connected with it. The corridor concept occupies a prominent place in several European reports. Albrechts and Coppens (2003) believed that the creation of corridors is related to SoPs and SoFs. Seven large corridors have been selected for the CORRIDESIGN Project of the Internet IIC, and the Brussels high Speed Train (HST) station has been introduced in detail in it. They defined the “corridor” as the virtual and physical infrastructure to realize the connection of main nodes in Europe. To obtain the operation process of this concept, they constructed a simple model is constructed, which includes three interrelated parts (actor, society, and space (including SoFs and SoPs)). Then, they made a case study of the Brussels high Speed Train (HST) station. Their studies make it utterly clear that SoFs often wipes out and replaces SoPs. According to literature (Stalder 2004), SoFs is formed gradually under the specific historical conditions. Mobile information, ICTs, and the joint of human and machine are the three major elements of SoFs. In SoFs, all levels of human activities are represented by dynamic rather than static. Heidenreich regarded SoFs as a bridge for technological and cultural exchange between society and nature, and studied the necessity of SoFs to society and nature in developing new cultural perception (Heidenreich 2009).

Reference Sun and Lu (2005) believed that SoFs is the external manifestation of geographic cyberspace. It is the dominant spatial form of the information society. The rapid development of ICTs promotes the flow frequency of element flows around the world, sequentially leading to the changes in corporate organization and economic organizational structure, and ultimately leading to the transformation of spatial form from static to dynamic, and from SoPs to SoFs. Reference Ai and Miao (2010) studied the SoPs and SoFs from the perspective of actor network. It argued that both SoPs and SoFs caused by the global flow of various element flows can be understood as the space of actor-networks formed by practices. Reference Shen et al. (2012) studied the concept of SoFs in the information society, and considered that the complete concept of SoFs should include five levels, that is, the study object, the basic process, the media, the important components, and the typical space of SoFs. Based on this viewpoint, SoFs was defined as the space that combining human activities and various kinds of flows as its research object, and taking ITs (such as electronic communication and Internet) and high-speed transport corridor as its support and media. Various types of flows circulate among nodes with similarities and

differences, and connect with each other in the process of flow. The spatial positions of these flows are shifted frequently and exchanged regularly. Traditional concepts of time, space, and distance have been changed because of the interaction of ITs, economy, and space. Reference Gao et al. (2012) discussed the relationship between SoFs and SoPs, and interpreted the basic connotation of SoFs under the framework of urban geography. It thought that the core of SoFs’ concept is the space field or carrier formed by a series of element flows under the guidance of information flow. It also discussed the necessity of the sinicization of SoFs’ concept by reviewing the study of SoFs in urban geography. Reference Liu and Yang (2014) explored the contemporary interpretation of Castells’s SoFs thought from the perspective of social media and social production of space. It thought that the production logic of current SoFs is still a kind of interest-function dominant space logic. This fact is consistent with Castells’s initial assumption. The difference is that SoFs shows instability and dynamic nature in the production. While providing people with different spatial experiences, SoFs has gradually influenced and transformed the mode of human daily life and production. On the basis of combing the current concepts of space, reference Dong and Li (2014) made a key study on the concept, characteristics, and basic structure of SoFs. It put forward some new understandings on the concept of SoFs in the information age, and emphasized the importance and dominant position of information flow in the formation and development of SoFs. Besides, it believed that knowledge and technology are the foundation of SoFs while information flow loading other elements is the main operating pattern of SoFs. In its opinion, information and communication network infrastructures are the neural network of the whole space. Reference Junwei (2014) held that Castells’s space theory is composed of the early urban space theory and the later SoFs theory.

Based on the research results above, this paper argues that SoFs is the product catalyzed by the development of ITs and economic globalization. Its core components not only include various element flows (such as information flow, capital flow, material flow, and population flow), the carriers of these flows (such as transportation network, Internet, and some other infrastructures) in the flow process but also the nodes in the flow links which can be either people or things. SoFs contains two levels of meaning: one is the “flow” which refers to the element flows and their flow characteristics while the other is the “space” which refers to the carriers and boundaries of these element flows. Accordingly, we can study the spatial pattern difference of each element flow, the influence of its carriers on its flow, and the status difference of each node during the flow process.

### Constitute elements of SoFs

The most prominent characteristics are liquidity and dynamic. The reason why it shows these characteristics is inseparable from its constituent elements.

### The fundamental constitute elements and their relationships

Referring to the thought of Wang (2016), we think that the composition of SoFs can be represented by the following figure (Fig. 2).

As shown in Fig. 2, the fundamental constitute elements of SoFs are the infrastructure and the space. In term of the infrastructure, it includes the road networks, Internet, telecommunication network, and so on. The infrastructure is foundation of SoFs. In term of the space, it includes many different kinds of element flows, such as population flow, material flow, capital flow, and information flow. These element flows continuously flow from one entity to another entity, thus forming different kinds of subspaces, such as population space, economic space, and information space. The flow of these element flows is inseparable from the support of the infrastructure. Furthermore, the flow of these element flows indirectly stimulates the construction and development of the infrastructure.

The flow of each element flow is inseparable from its corresponding carrier. The carrier can be a person, a product, a place, an so on. Each participant (entity) in SoFs can be abstracted as a node. These nodes are connected

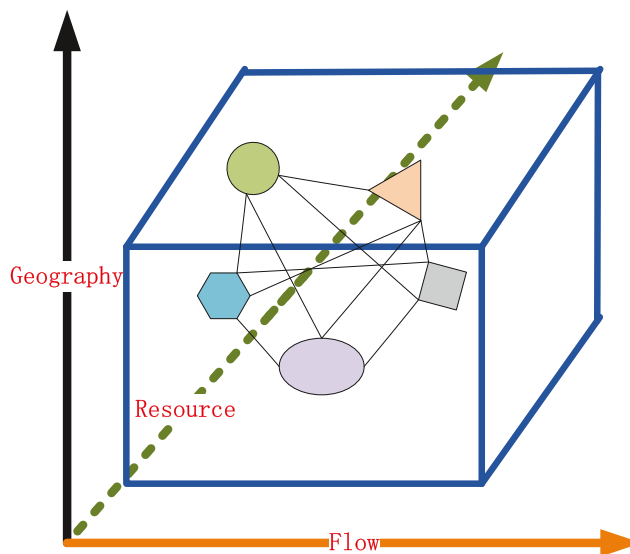
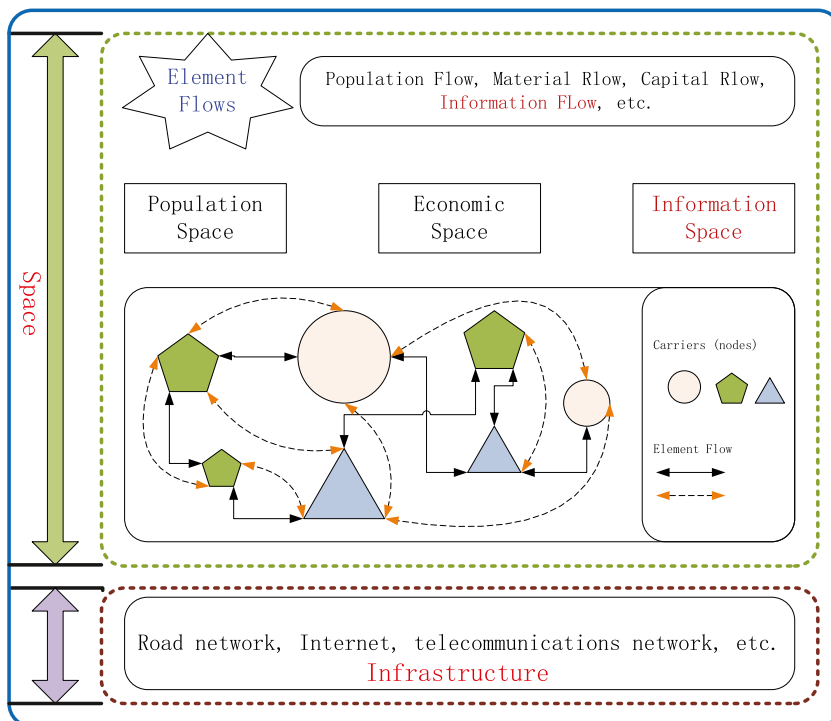


Fig. 3 Three dimensional properties of SoFs

to each other through the flow of each element flow. Meanwhile, the properties of these nodes are diverse. From this point of view, SoFs can be seen as a three-dimensional space. The three dimensions are geography, resource, and flow respectively (Fig. 3).

Among these dimensions: the “geography” dimension mainly refers to the location information (such as longitude and latitude, IP address) which can be used to distinguish each node uniquely; the “resource” dimension refers to the different conditions of each node (such as population size,

Fig. 2 The composition of SoFs



economic development level, natural resources storage); the “flow” dimension refers to each element flow and its flow process.

Furthermore, in order to describe SoFs more clearly and completely, we regard SoFs as a system, and design a 4-tuples ( $ss$ ,  $fs$ ,  $ds$ ,  $as$ ) for representing it. In the tuples,  $ss$  stands for the set of static attributes of relevant entities in the space (such as population size, mineral reserves);  $fs$  stands for the set of factors that affect the flow of each factor flow, and can be divided into controllable factors (such as policy guidance) and uncontrollable factors (such as natural disasters);  $ds$  is a state description set that describes the specific flow situation (such as the starting point, intermediate node and end point of the flow, the direction of the flow, the volume of the flow, and so on);  $as$  is a set of related methods and algorithms used to describe the differences in the attributes of each entity, the correlation between each factor and the flow of each element flow, and to evaluate or predict the flow of each element flow.

### The functions, definition, and correlation of the core constitute elements

We regard some kinds of element flows as the core constitute elements of SoFs. These flows include material flow, population flow, information flow, capital flow, technology flow, and so on. Among them, the first four types of element flows are the most popular research objects.

#### Definition and function of material flow

Material usually flows along certain paths. Its forms and modes may vary at different stages of flow. In general, the flow process of material can be divided into two main stages, namely, the flow on production lines and outside production lines (Long 2009). The flow on production lines refers to the process in which various raw materials are finally formed into products through a series of processes. The flow outside production lines mainly refers to the process from the end of the production lines to consumers (namely, the management discipline referred to as “logistics”). The flow process of materials follows the production processes and production instructions. In addition, the material flow can also be divided into production element flow and product flow according to the nature of the material itself. Production elements mainly flow on the production line. Their principal role is to maintain the sustainability of production and consumption. The product flow usually flows outside the production line and expands its sales coverage and influence in the continuous flow process. Its role is to meet the daily production and life needs of consumers.

Many scholars, especially in the field of economics, usually regard production element flows as the premise

and basis for economic links among different regions. They argued that the regional economic development and growth rate mainly depend on the subjective willingness of economic contacts, and the external effects of production element flows and product flows. Material flow affects the growth of regional economic from two different aspects: (1) material flow is conducive to the deepening of regional division of labor and specialized production as well as the effective input of production elements; (2) material flow can expand the output demands (Chen and Zhang 2010). The flow direction and intensity of material flow among economic linkages play a vital role in the quality and speed of economic development in the corresponding regions.

In addition, the flow path of material in time dimension not only reflects the dynamic relationship of the flow but also reflects the time sequence, accumulation, and consumption of material in each flow link. All the flow links are accompanied with the generation, transmission, and utilization of information, thus forming information flow. So we can say that material flow is the carrier of information flow.

#### Functions of population flow

People usually flow purposefully and directionally for survival, development, schooling, and family or friendship maintenance. The migration even has a “seasonal” nature. For example, during the Spring Festival, population migration is the most active in mainland China: a large number of migrant workers migrate from their workplaces to their hometowns before the festival and return after the festival.

The impact of population flow is double-edged. Taking mainland China as an example, at present, the economic development level of each province and city is quite different. To improve their living conditions or to play their talents better, a large number of labor force flow from the relatively backward provinces and cities to the economically developed provinces and cities (such as Beijing, Shanghai and Guangdong). On the positive side: (1) for the inflow regions, labor force injection has made unparalleled contributions to their infrastructures’ construction, scientific research and education, health care, and economic development; (2) for the outflow areas, after these migrants obtaining their desired results, benefits or income, they may bring their tangible wealth (such as money) and intangible wealth (such as technology, experience) home, which will stimulate and promote the construction of their hometowns and the expansion of their fellows’ knowledge. On the negative side: (1) for the inflow regions, the influx of large number of people puts forward higher requirements on health care, accommodation, transportation, public safety, education,

and many other aspects of infrastructure facilities. Local governments must address these migrants' basic needs such as food, clothing, housing, transportation, and even education. (2) for the outflow regions, exporting large number of young labor has greatly slowed down the speed of their economic constructions and developments. It also causes a large number of left-behind elderly and children, and a series of social problems.

Population migration and its impact is a very complex research topic. Many researchers can only choose a more specific sub topic for research. For example, most of them focus on the impact of population mobility on regional economic, urbanization development (Wu and Zhao 2010; Du and Chen 2010; Yang et al. 2011; Zhao et al. 2013; Li et al. 2015)) and some other aspects (Chen et al. 2009; Gao and Wu 2012; Niu 2013; Zou and Wu 2013; Zhang 2015b). The relationships between population flow and other element flows are mainly listed as follows:

- Population migration will have varying degrees of impact on the economic development of the inflow and outflow regions. Generally speaking, the greater the quantity and quality of population inflow, the more important it is to the economic development of the inflow regions, but the greater the adverse impact on the economic development of the outflow regions.
- Population migration plays a guiding role in the flow of material and capital. For example, a delegation from a company in place *A* goes to place *B* to negotiate business with a local company. After their successful negotiations, two companies may exchange goods and capital.
- The flow process of population is bound to be accompanied by the dissemination and flow of information. It is worth emphasizing that population migration, especially the migration of the social elite stratum, is an important component of SoFs structure described by Castells. The relation assets (e.g., the interpersonal network and the sense of trust) which are established by people through communication with each other, have been playing more and more important role in regional economic development (Miao et al. 2011).

### Definition and function of information flow

Information flow refers to the process of information capture, processing, utilization, and transmission. In the flow process of population and material, a large amount of information will be generated inevitably. These information are stored, processed, utilized, and transmitted among different entities in various forms. They can regulate and guide the flow of population, material and capital.

Participants in the flow process of information usually include information producers (senders), information receivers, and information dissemination media (communication channels). Information receivers passively or actively receive information transmitted from information producers. This transmission process often depends on some specific information media. There are neither absolute producers nor absolute receivers. Their roles change frequently. The flow process of information can also be divided into two modes: direct communication and indirect communication (Fig. 4). Comparatively speaking, the direct communication mode is more greatly restricted by time and space.

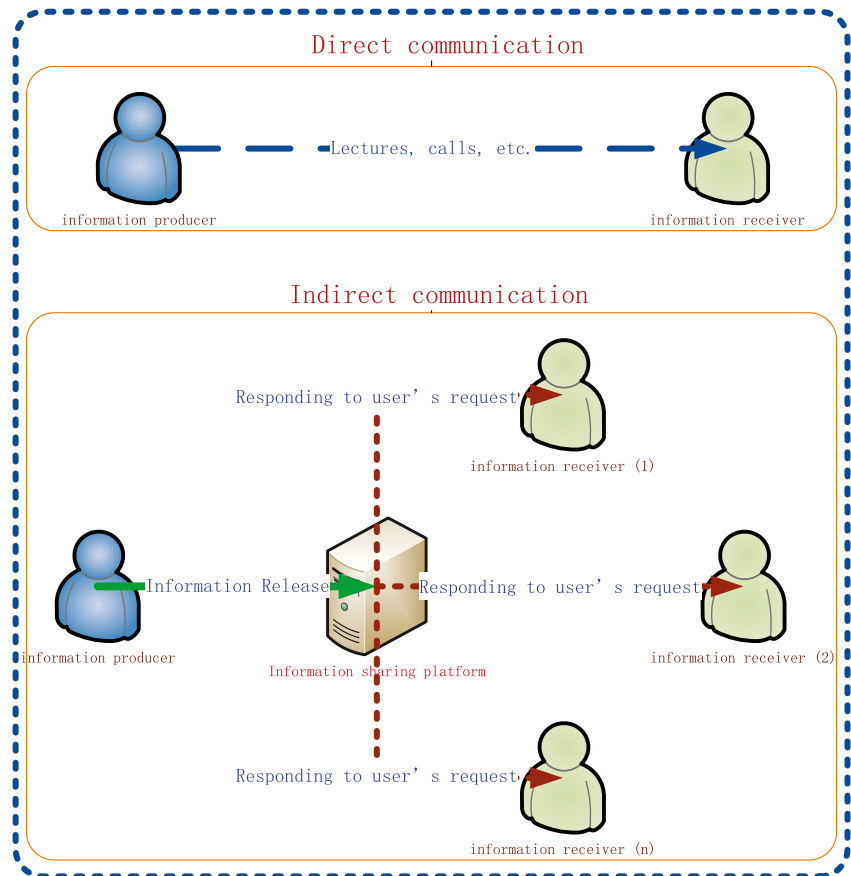
Further, information flow can also be divided into three types according to the attributes of information producers and receivers, that is, interpersonal information flow, organizational information flow (two subtypes: vertical communication, lateral communication), and mass information flow (Zhang 2000). The concrete definition and comparison of these flows are shown in the following table (Table 3).

Information flow can guide the flow of population, material, and capital in two aspects. It can not only positively stimulate the flow of other element flows but also block them. Taking Internet shopping as an example, the evaluation of goods made by early purchasers largely determines the purchase willingness of future purchasers. If many purchasers have given negative comments on one product, others will not buy it again, thus blocking the flow of capital. On the contrary, positive comments will attract more purchasers and bring more capital flows.

In addition, in the context of information society and knowledge economy, information is not only a product but also a raw material for production. The ability differences in information manufacturing, storage, processing, utilization, and transmission among different entities can be expressed as "information potential." The level of "information potential" determines the status of interrelated and competing entities in their interactions. The region with a higher level of development and perfect information infrastructure usually has a higher "information potential." The guide role of information flow to other flows in this region is very significant. In addition, this region is often in a dominant position in foreign exchanges and contacts. Besides that, it usually has a strong attraction to other regions. It should be pointed out that the guidance intensity and scope of information flow largely depend on the construction level of information infrastructures and relevant systems (such as information supervision systems and integrity systems). Therefore, the influence of information flow on regional spatial interaction is different under different economic, social, and cultural backgrounds.



**Fig. 4** The flow process of information



**Table 3** Definitions and comparison of the three kinds of information flow

Type	Definition	Characteristics
Interpersonal information flow	Information exchange between individuals and individuals. It is usually two people (or more) who communicate with each other because of a common interest or to achieve the same goal.	Spontaneity, flexibility
Vertical communication	Upward flow: Information flows from a lower level to an upper level in an organization. It is an important way for leaders to get feedback information. Down flow: Information flows from an upper level to a lower level in the organization. Superiors usually transmit information to the lower levels in the form of documents, instructions and meetings.	Confidentiality, unidirectionality, hierarchy, authority
Lateral communication	Communication between the intermediate levels of social organizations. For example, the flow of information between enterprises, producers, manufacturers, raw material suppliers and distributors.	Publicness, bidirectionality, persuasion, equality
Mass information flow	Use mass media to spread information to the masses on a large scale.	Spread fast, wide range of transmission, not limited by time and space, with vague purpose, unidirectional transmission

## Function of capital flow

Compared with other element flows, capital flow usually occurs after the flow of information or population, and before or after the flow of material. Taking online shopping as an example again, consumers will inevitably understand the relevant information about commodities through appropriate channels before they decide to make purchases. After confirmation of the purchase, both cash on delivery and online payment can be selected. Under these two different modes of payment, the flow processes of different element flows throughout the transaction are shown in Fig. 5(a) and (b), respectively.

From the perspective of consumers: (1) Their needs on production and living, work and leisure can be met by means of the flow of capital; (2) With the outflow of capital, they are bound to work hard to supplement their savings. By this way, they will do more contributions to their workplaces while maximizing their own value. From the perspective of businesses, with the inflow of capital, enterprises can not only survive in the competition but also continue to grow and expand through improving the treatment of employees, introducing new production technologies or equipments.

Due to the demands of production, life, and some other aspects, people inevitably have to obtain commodities, technologies and, other necessities from other people, groups or companies, thus triggering the flow of capital. Although capital flow is not the first to occur, its existence is

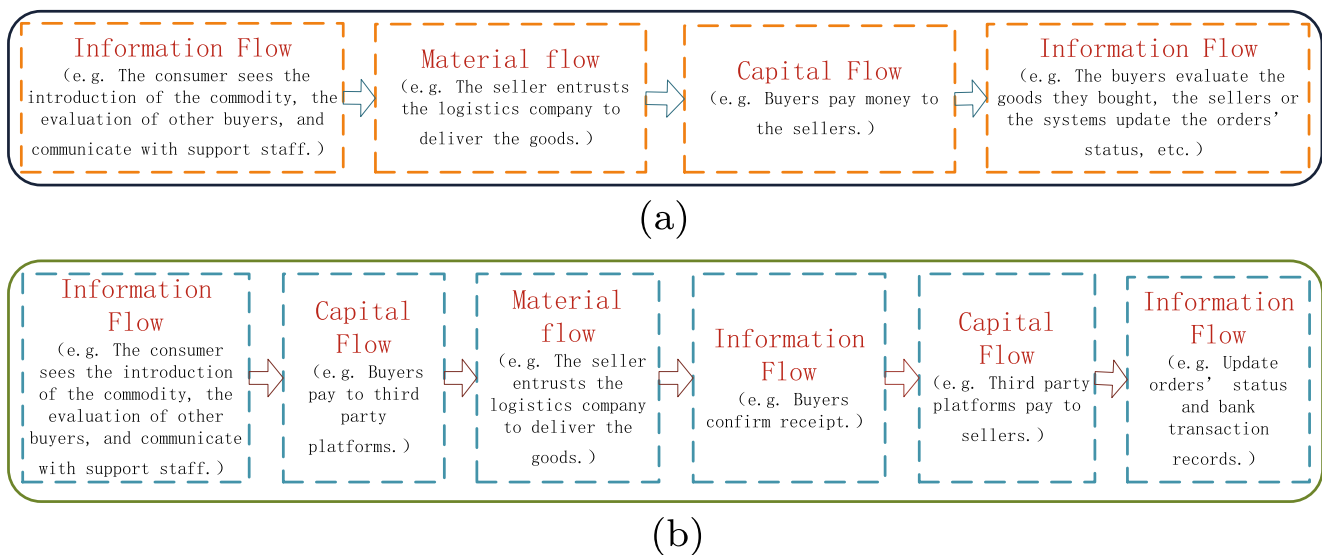
an important guarantee for the flow of population, material, and information.

## Correlation among different types of element flows

The flow of material, capital, and information is usually accompanied by the flow process of population. In addition to the population flow, material flow is the guarantee while capital flow is the means of realization. Meanwhile, information flow is the core and basis of material flow and capital flow.

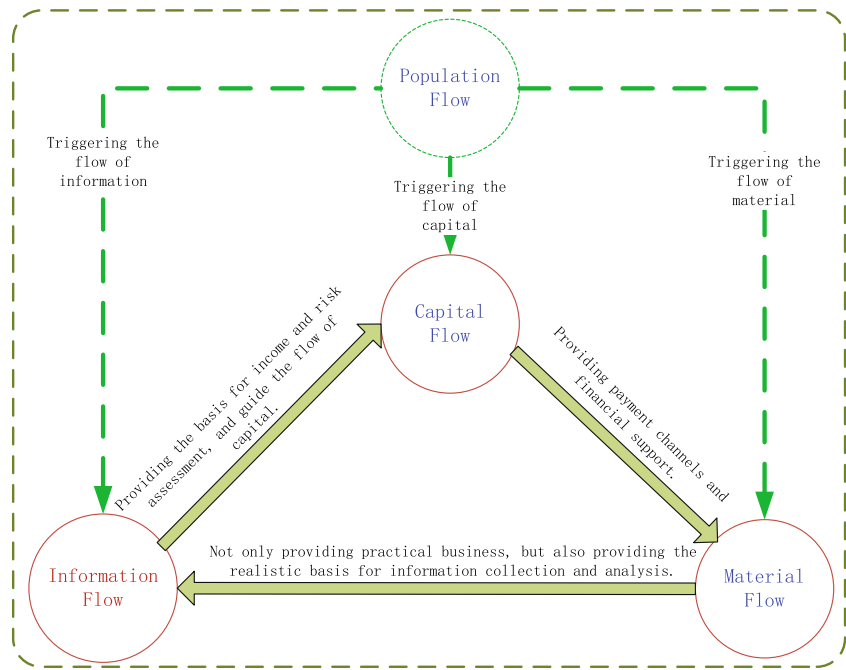
In the era of big data, the relationships among the three kinds of flows are shown as follows: (1) capital flow provides financial support and payment channels for material flow; (2) material flow provides real businesses for information flow, and provides a realistic basis for information collection and analysis; (3) information flow can not only guide the flow of capital but also provide cost-benefit analysis and risk control for it Xue (2014) (Fig. 6).

In the information society, people's production and life activities are no longer limited to the traditional SoPs but extended to SoFs. Information flow is guiding the developments of other element flows in a more rational and orderly way. Information flow, capital flow, and material flow can be used as the important indexes to evaluate the intensity of network links among the relevant regions. In social and economic life, with the separation of business flow, material flow, and capital flow, the role of information flow is becoming more and more important.



**Fig. 5** Element flows' flow process in different payment modes

**Fig. 6** The relationship among the four kinds of element flows



**Correlation and comparison between SoFs and SoPs**

SoFs is the product of the development and application of information technologies. It has integrated with SoPs to form a new kind of space. At present, we are in this new space, so it is necessary to clarify the differences and connections between them.

**The difference and relationship between SoFs and SoPs**

In the information age, urban space is gradually filled and knitted by various element flows. Eventually, this phenomenon and fact leads to the weakening of the original boundaries of urban physical space. The location theory has been gradually replaced by relational theory (Flusser 1991). SoFs is the space that carries the flow of these element flows. It is reshaping the regional and spatial structures. The

comparison results between SoFs and SoPs are shown in the following table (Table 4).

The rapid development of ICTs has led some researchers to claim that the significance of SoPs is gradually diminishing, thus putting forward the conclusion of “distance extinction and geographical end.” Opponents argue that the alternative role of SoFs triggered by the development of ICTs is still limited. Although remote network information interaction has become an important means of communication among related entities, it still cannot replace the face-to-face communications completely.

By contrast, we prefer to accept the latter viewpoint. Firstly, it is undeniable that more and more activities can be performed in SoFs created by the development of ICTs. The location function of SoPs is more dependent on the organization of SoFs, which means the impact of SoFs on the SoPs is increasing. However, SoFs has not fully penetrated into all areas of human social practices yet. Secondly, transferring relevant activities from SoPs to

**Table 4** Comparison between SoFs and SoPs

	SoFs	SoPs
Constituent elements	All element flows + point, hinge	Point, line, surface
Driving factors	ICTs	Economy
Scale boundary	Not affected by scale; blurred boundaries	Affected by scale; clear boundaries
Distance influence	Time-space compression; distance extinction (weakening)	An important factor
Contact mode	Perpendicular to the horizontal; bidirectional; network	Perpendicular; unidirectional; hierarchical
Architecture	Networked architecture	Single centripetal system

SoFs can greatly break through the limitation of time and geographical distance with the help of the instantaneous fluidity of information, and thus reduce the influence of geographical distance. However, the geographical location attributes of the participants themselves are usually fixed. Furthermore, although SoPs is constantly impacted by SoFs, it will not disappear. “Places” also exist in SoFs. With the help of network, the effective combination of SoFs and traditional SoPs is realized by connecting specific or different place nodes (Sun et al. 2005). SoFs depends on SoPs, but it also surpasses SoPs. These two spaces will coexist for a long time.

### The embodiment of the three space elements in SoFs

“Location,” “distance” and “direction” are the three fundamental elements of space. The interrelationships among them constitute the internal relevance of space. In SoFs, each participating entity has its own “location.” There is a “distance” between one entity and the others. All the element flows in SoFs are flowing from one entity to the others with the reason of demand, attraction or external forces.

#### The power of “location”

Mobility is one of the main characteristics of SoFs. Different participants establish their connections with the aid of different types of element flows. The higher the flow frequency and the greater the circulation of the element flows will make relevant participants more closer with each other. The variety and multi-dimensionality of the element flows make the relationships among the corresponding participants present a certain multi-dimensionality. Participants can be abstracted into network nodes, while the connection relationships established by the flow of element flows can be abstracted into the edges among these nodes. By this way, a directed (considering the flow direction of the element flows) or an undirected (not considering the flow direction), weighted (considering the connection intensity) or un-weighted (not considering the connection intensity) regional network will be formed. Each node plays a different role in the overall network (such as core status, hub status, and edge status).

The power of “location” is mainly reflected in the following two aspects:

- **Centrality.** In SoFs, a participant makes full use of its high information potential to elevate itself to the central node, strengthen its authority, attract more participants’ attention, and sequentially form centrality. The so-called “information potential” refers to the ability differences in the manufacture, storage,

processing, utilization, and transmission of information among different entities (Jinming 1996). The region with higher information potential is bound to have a higher level of information infrastructures. In this region, information flows faster accompanying with larger information circulation volume. This makes the probability of the flow of material and capital far greater than that of the regions with lower information potential. In addition, in the regions with higher information potential, element flows are more inclined to flow within these regions or flow to some other regions with similar or higher information potential. In contrast, in the regions with lower information potential, element flows are more proactive to flow to the regions with higher information potentials.

- **Difference in opportunities.** In SoFs, participants with different information potentials usually have different social, economic, and cultural conditions. The main differences are shown as follows: (1) the core participants have more initiatives in the process of cooperation and competition with other non-core participants; (2) the core participants can enjoy more development opportunities; (3) the core participants are more capable of creating and providing more opportunities to others.

We think that the user influence analysis method in social network (Zhang 2015a) can be used as reference to describe the influence of one participant on the others in SoFs. The formula is defined as following:  $L_t(a) = \sum(l_t(p_f(a)))$ ,  $p(a) = \sum(w(m(b, a)))$ , where  $f \in F$ ,  $(b, a) \in E_t$ . Meanings of each symbol in the formula are listed as following.

- $F$ : the set of various types of element flows in SoFs.
- $p_f(a)$ : the deep influence of region  $a$  on the flow  $f$ .
- $(l_t(p_f(a)))$ : the sum of the breadth and depth of region  $a$  on the flow  $f$  in the time interval  $t$ .
- $L_t(a)$ : the sum of the influence of region  $a$  on all types of flows in the set  $F$  within the time interval  $t$ .
- $p(a)$ : a quantitative function of the flow volume of a certain type of flow between other regions and region  $a$ .
- $m(b, a)$ : the flow volume of a certain type of flow from region  $b$  to region  $a$  in the time interval  $t$ .
- $w(m(b, a))$ : the quantitative value of the influence of the flow volume  $m(b, a)$ .

#### The influence of “distance”

“The first law of geography” holds that “geographical objects or attributes are interrelated in spatial distribution, while similar things are more closely related to each other” (Tobler 1970). The difference of “distance” leads to the difference of status and opportunity, and eventually

shows the difference of “core” and “edge.” The old saying goes that “a near neighbor is better than a distant cousin.” It intuitively expounds the influence of distance on interpersonal relationship. With the emergence and promotion of social networking services and platforms, the scope of interpersonal communication has broken through the limitations of traditional geographical distance, so that a “distance extinction theory” came out (Cairncross et al. 1997). However, subsequent studies have found that the impact of distance on interpersonal relations not only exists in real society, but also exists in virtual cyberspace.

Space-time accessibility of traffic (StAoT) is an important factor that not only determines whether there will be a correlation among entities in real geographic space but also determines the intensity of their correlation. In SoFs, the impact of StAoT is mainly embodied as the impact of road, Internet, and some other infrastructure construction level on the flow patency of each element flow. Under the same flow driving forces and other conditions, element flows will flow smoother in those regions with higher levels of infrastructure constructions. The most direct and obvious manifestation is the shorter flow time from the beginning to the end. There have been many studies on the accessibility of transportation networks (including railway network (Fengjun and Jiaoe 2004; Willigers 2006; Emilio et al. 2011; Zhao 2015), road network (Pendleton 1963; Roehl et al. 1993; Xiaoshu et al. 2005; Yujuan and Xiaoshu 2010; Mei et al. 2013), and air network (Sheng 2015; Li and Wang 2017)), and Internet. All the results of these studies have shown that StAoT is an important factor affecting the velocity and volume of each element flow. From the perspective of the main media which it depends on, population flow and material flow depend more on the construction of railway, highway, and aviation network, while information flow and capital flow mainly depend on the improvement of Internet infrastructures.

### The embodiment of “direction”

Various element flows flow in SoFs either complying with subjective wills or being forced by some external forces. They may flow with definite purpose or aimlessly. The flow process from the beginning to the end can be either a direct line or a polygonal line, while the flow direction can be either one-way or two-way (Fig. 7).

The flow direction of population depends largely on the flow reasons. People move purposefully to the places where their needs (such as work, study, medical care, shopping, entertainment and so on) can be met. After their needs being met, they may return to their origins or move to new places for new needs. Apart from the above subjective wishes, population may also move passively and purposefully or

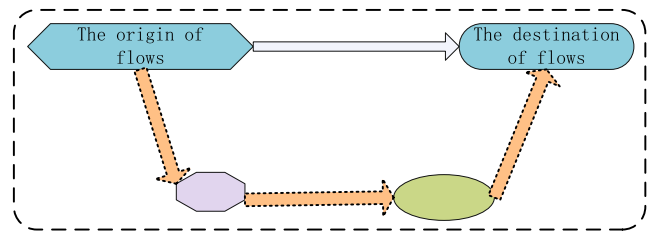


Fig. 7 The paths of flow

aimlessly forced by external forces (such as natural disasters and wars).

Material usually flows from the starting point of a production line to the end point, and then from the manufacturers or agents to the consumers due to the market and consumers’ demands. Generally, the flow direction of material is usually one-way, but sometimes may be two-way (e.g., if a consumer requests a return for subjective or objective reasons, then the product or material will return to the manufacturers or its original owners after they reach a consensus in consultation).

The main flow direction of capital is from consumers to the providers of products or service, or from employers to their employees. Occasionally, it maybe flow reversely, such as the return of merchants and consumers’ claims for refunds.

The flow of information flow is more complicated than that of the former three kinds of flows. On the one hand, the flow of the three kinds of flows cannot avoid generating information and flow of information. Then, the former flows are also guided by the information flow. On the other hand, information can flow not only between people and people, people and things but also things and things. Furthermore, the flow of information can be one-to-one, one-to-many, many-to-one or many-to-many. In terms of the flow direction of information, it can either flow from its producers or owners to some specific targets, or be spread at will in the case of uncertain objectives (e.g., the advertisements broadcast on radios). It should be pointed out that: (1) information may be acquired intentionally or unintentionally by non-designated targets (such as hackers) under the flow process to designated targets, and then new flows will occur; (2) in the flow process of information without designated targets, it may attract relevant targets’ attentions, and then produce purposeful transmission.

### Interaction mechanism of SoFs

In the traditional concept of space, an entity space or region has a definite location and time. There are certain differences among regions. However, with the

development of ITs, since the 1990s, human beings have entered an information-oriented society. Not only the concepts of time and space but also their relationships have been changed. The traditional agricultural and industrial economy (characterizing by “angible material flow,” and mainly relying on transportation networks to link production and consumption) has been transformed into a knowledge-based economy (taking the transmission and processing of “invisible information flow” as its main content, and taking the information infrastructures and information network system as its core medium) (Zhang 1998). How does SoFs come into being and development? How do the entities in SoFs interact with each other? It is necessary to explore these issues.

### Information guidance mechanism for the formation and development of SoFs

Data are the original records of objective things. They are unable to answer any specific questions unless they have been processed. Raw data do not establish links with each other. They are scattered and isolated. Information is the use of technical means to process the original data in order to discover the internal association of them. It can be used to answer specific questions such as “why,” “what,” “where,” “when,” and “how.” Once information is formed, it can be widely disseminated, shared, and updated. Knowledge and experience would be formed, if information is used to guide production and life practices.

In the era of big data, data is wealth. However, having huge amounts of data is only the necessary condition for success rather than the necessary and sufficient condition. The value of data cannot be realized without knowing how to use it. So, we must try to mine valid data from raw data, and discover the association among them. “Big data” is characterized by large volume, low value density, variety, and fast velocity. It is precisely because of these four characteristics, resulting in the difficulty of mining, and putting forward high requirements on mining tools and mining performance. Big data mining involves a large number of high-tech, such as large-scale parallel processing database, distributed file system, distributed database, scalable storage system, and cloud computing platform.

SoFs is a new form of space produced under the impetus of information technology in the process of globalization. It is the result of information technology reform. The need for processing massive complex data has stimulated the development of ICTs, which in turn has an impact on the development of SoFs.

### Information flow acts on the evolution of economic and social structure

The development of ICTs has created an open electronic regional space. Production, education, entertainment, and daily life in the region are carried out in this space. Information flow has gradually become an important component of regional space. It takes infrastructures (such as Internet, telecommunications networks) as a medium, and flows among participants in the region according to certain rules. Regions with economically developed and frequent information activities are usually the active regions of information flows. In the frequent flow process of information, material, and capital around the world, the spatial form has changed from static SoPs to dynamic SoFs. It finally affects the development of regional economy (Sun et al. 2005).

The development of financial geography can be divided into three stages. They are the stage of location choice theory, the stage of financial geography theory, and that of information flow theory, respectively. The information flow financial center theory fully combines the background of information society, and emphasizes the leading role of information in the forming process of financial centers. It has become one of the most frontier research fields of financial geography. The main viewpoints of this theory include the following: (1) Information flow is a prerequisite for the development of financial centers. (2) Financial centers are usually responsible for sublimating low-level information into organic information while collecting and using information. The financial industry can also be described as “high value-added” information service industry. (3) “Information externality” and “information hinterland” (the area where information flows at the lowest cost, the highest speed, and the highest credibility; usually the sources, gathering points or disseminations of information), “asymmetric information,” “international dependence,” and “path dependence” are the determinants of the status of financial centers. (4) “Path dependence” and “information externality” theories can help us understand the factors that dominate financial centers in the region while “information hinterland” and “asymmetric information” theories can effectively explain why traditional financial centers have been replaced (Thrift 1994; Porteous 1995; Gao and Yao 2007).

The research results on the influencing factors of the transmission of information flow (Zhao et al. 2002; Wu and Lu 2007), the distance attenuation pattern (Du et al. 2008; Lu et al. 2010), and the relevant methodologies (Bakis and Zi 2000; Li and Lu 2006; Zhang and Lu 2011) have laid a foundation for the study of the influences of information flow on economic spatial structure. The growth mode

of economic has been transformed by the development of ITs: (1) Technological innovation in ICTs sectors has led to a continuous reduction in the manufacturing cost of information and communication equipment. Further, it brings a rapid decline in market prices, which directly stimulates the various economic sectors to increase their investments in ITs, and finally resulting in the deepening of IT capital (Zhou 2010). (2) The popularization and wide application of IT products, and related technologies not only improve the productivity of the product users or technology owners but also affect the mode of other economic sectors' economic activities, thereby realizing the flow of products and technologies among all economic sectors. Eventually, it is helpful to improve the efficiency of market transactions and promote the transformation of the economic growth pattern (Zhu et al. 2016).

At present, ITs has replaced the traditional production elements, such as labor capital and land, and become the core driving force of economic growth. The position of a region in the market competition determined by its "information potential." If a region wants to occupy a vantage position in the market competition, it must try to improve its informatization level and "information potential" to ensure the effective and smooth flow of information.

- *By stimulating the development of ITs, information flow can affect all aspects of human production and life.* The important role of ITs in social and economic development is mainly embodied as follows:
  - *ITs can trigger the transformation of economic growth form.* ITs have shifted the focus of social production from material and energy production to information production, dissemination, and utilization, thus promoting the transformation of industrial economy to knowledge economy, and eventually evolving into a virtual era and digital era. They have also given birth to the informationization model of economic growth, and provided technical supports for various countries and regions to solve the problems of high investment, high consumption, and high pollution, thus contributing to the realization of sustainable economic development.
  - *ITs have promoted the rapid development of information industries.* ITs and information industries have become the foundation for new economic development. The most direct and effective evidence of this is the proportion of the third industry in the national economy has been continuously increasing: (1) while ITs are widely used in all walks of life, they have

constantly brought the changes in traditional industries in terms of information acquisition, transmission, and utilization, thus bringing significant impacts on the development of various industries. (2) with the rapid development of ITs which mainly focuses on communication, software, and information services, each country and region has attached great importance to the adjustment of industrial structure and strived to enhance the proportion of the information industries in its economic structure. (3) information industries not only provide ITs, information services, and information equipment for traditional industries but also promote and accelerate their upgrading in order to enhance their viability and competitiveness.

- *The flow of information in a wide range, large volume, and high frequency has constructed a highly informationalized information space.* With the spread and interweaving of information flow in the world, globalized and highly informationalized information space has been gradually formed. In this space, relying on the material support of SoPs, and taking the information flow as the carrier, each entity acts on various economic and social activities within the region, thus realizing the reconstruction of the regional spatial structure. With the continuous flow of information in the region, a new paradigm of economic and social development has finally been formed. The new paradigm takes information collection, processing, utilization, and transmission as its main content, while taking information and communication infrastructure construction as its path. Its influence on economic and social practice activities can be achieved with the help of information real-time interaction (Dong 2012).

In conclusion, the traditional material economy, which takes the production, circulation, and consumption of materials as its main characteristics and objectives, has been gradually replaced by the information economy characterized by information acquisition, processing, and utilization. Information and knowledge have become the core drivers of economic growth. The information flow in SoFs breaks through the limitations of geographical space, and flows widely around the world, thus strengthening the links among the economic entities. Economic globalization and transnational cooperation have long been the major trend of world economic development. Cities, as the nodes of the global economic network, are connected to each other through the Internet. They are not only the centers of people's production, life, and economic activities but also the gathering places of international information flow, population flow, material flow, and

capital flow. Their 'information potential's determine their positions and competitive power in economic exchange activities. Therefore, cities must strive to improve their informatization levels, and enhance their abilities to manufacture, capture, process, and use information. By promoting the development of information industries and the full integration of production sectors, information circulation can improve the production efficiency and change the structure of regional industries and economic society. In addition, information is produced all the time. The huge information flow requires that the relevant entities in the flow process must have the ability to deal with them quickly. Otherwise, it will become the bottleneck of these entities, and even that of the whole economic society's development.

### Formation and development of SoFs guided by information flow

The information society mainly includes and integrates land elements, social elements, network elements, and information elements. These elements interact with each other to form an information geographical landscape, which can be represented by the following matrix.

$$\begin{bmatrix} L_1 & L_2 & \dots & L_n \\ S_1 & S_2 & \dots & S_n \\ N_1 & N_2 & \dots & N_n \\ I_1 & I_2 & \dots & I_n \end{bmatrix} \quad (1)$$

In the matrix above,  $L_i$ ,  $S_i$ ,  $N_i$ , and  $I_i$  stand for a certain land element, social element, network element, and information element, respectively. Because of the participation of information elements and network elements, the modern information society is quite different from the earlier society (farming society and industrial society). The information elements and network elements make the information society have the characteristics of smoothness, maturity, development, agility, vitality, and economic benefits.

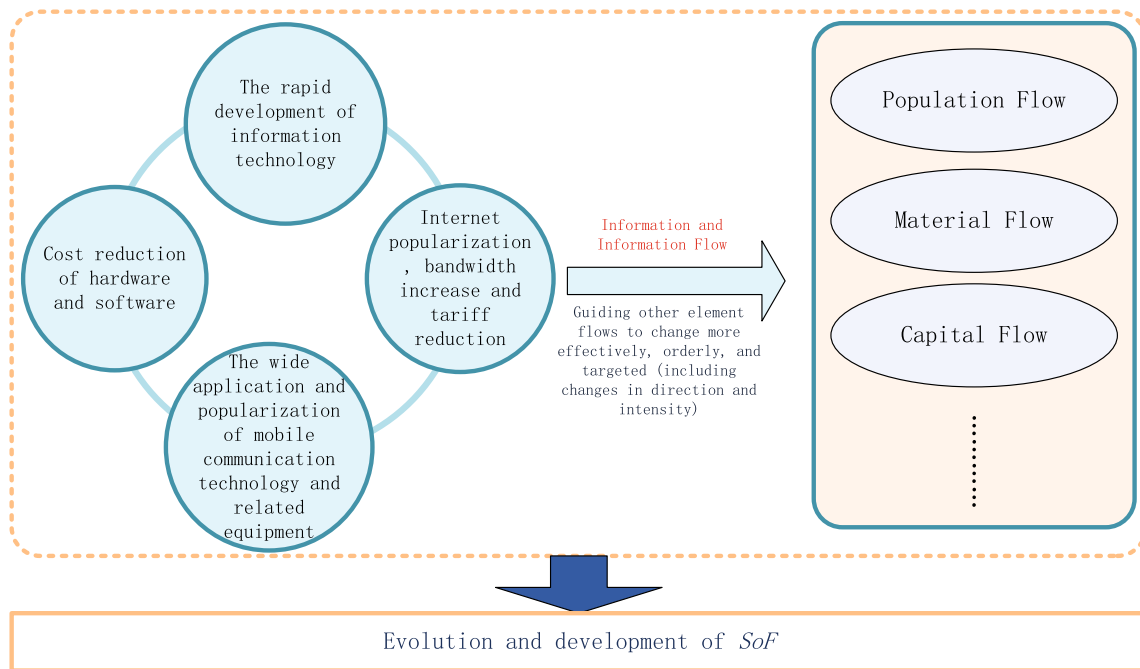
With the development of ICTs, the current new economic form presents the trend of globalization and informatization. In the new economic system, the productivities and competitive powers of economic entities depend on the amount of data, information, and information processing technologies they own. It is necessary and sufficient for an economic entity to have the data and information needed for production and the corresponding processing technologies. Globalization is reflected not only the global cooperation in the production processes but also the global flow of products and raw materials, as well as the flow of capital, labor, information, and technologies among relevant participants. Information takes the Internet and other infrastructures as its carriers. It cannot only guide effective cooperation but also guide the flow of raw materials in a directional and targeted

way. Besides, it can provide decision-making supports for the rational allocation of capital and labor, thus promoting the adjustment and reorganization of the regional economic structure and industrial layout.

In SoFs, information flow, material flow, population flow, capital flow, and many other factors coexist and interact with each other, thus forming a "flow cluster." Other element flows attach to information flow and depend on its guidance and management. Knowledge and technology, information and communication infrastructures are the basis and neural network of SoFs, respectively. The entities involved in the process of information transmission can be treated as nodes of the neural network. These nodes communicate and transmit information through the information communication infrastructures. However, their positions in the process of communication and transmission, and contributions to the whole network are different. The dominant governments and information mastering organizations are the core nodes of the whole network (Dong 2012). The flow of information also shows the centripetal force in the space, which is represented by the continuous concentration of information to the pivotal nodes (Zhang et al. 2001). For the participating entities in SoFs, the differences in the capabilities of information acquisition and processing are reflected in the differences of their "information potential." The unbalanced application of ICTs leads to the difference of "information potential" and the unbalanced development of regional spatial production, and even polarization. The participating entities in SoFs constantly try to improve their own "information potential" in order to have more initiatives in competitions. By this way, it eventually brings the continuous changes of the space, industrial structure, and spatial layout. Figure 8 shows the evolution and development process of SoFs, and the role of information and information flow in this process.

Generally speaking, the information guidance mechanism is the pivot of the formation and development of SoFs: (1) The wide application of ITs has promoted the development of information industrialization and industrial informatization. Entities with high "information potential" have become the cores of the whole space. (2) The core of ICTs is information processing and utilization. With the flow of information, human production mode and their social relations in the production process are continuously changing. It is finally transformed into information flow and information network, which lays the foundation for the generation of SoFs. (3) The guiding role of information flow makes people more and more emphasize the interaction and connection among regions, and leads to the fragmentation of spatial patterns of human behaviors. Essentially, it provides behavioral supports for the formation and development of SoFs.





**Fig. 8** Evolution and development of SoFs

**Interaction mechanism of SoFs**

Spatial interaction refers to the purposeful flow of population, material, capital, and information among cities or regions in the space. Because of the needs of production, life, and development, it is inevitable for one region to carry out the flow of element flows with others. With the influence of spatial interaction, previous separated regions are constantly combined into organisms with certain structures and functions (Xu et al. 2003).

On the basis of Ohlin (1933) and Stouffer (1940), literature (Ullman 1957) referred to the relevant theories of statistics, economics, and physics, and then from the perspective of supply and demand, held that the generation of spatial interaction should have three conditions, namely, “complementarity,” “intervening opportunities,” and “transferability”: (1) “Complementarity” — what one entity owns and can provide is exactly that needed by others. (2) “Intervening opportunities” — the factors that change the pattern of interaction in the original space. For example, because of the intervention of *C*, *A* temporarily decides to terminate the transaction with *B* and then turns to trade with *C*. (3) “Transferability” — We argue that it is more reasonable to replace “transferability” with “accessibility,” because the concept of “distance” is not limited to the traditional geographical distance. The construction and development levels of transportation networks and Internet infrastructures have become the most important factor in deciding the possibility and efficiency of mobility. Reference Haggett (1965) referred to the three ways of heat transfer in physics, and

then divides the forms of space interaction into three types, namely, “convection,” “conduction,” and “radiation”: (1) The main content of “convection” is the movement of population and materials, such as the migration of population among different regions, and the transportation of raw materials needed for production between the producing and consuming areas. (2) “Conduction” is mainly manifested in the flow of capital in various trading processes. (3) “Radiation” mainly refers to the diffusion of technologies and the flow of information. Reference Tan and Li (2001) pointed out that spatial interaction is based on natural resources, and took combined productions and commodities as its main line and main medium, respectively. Reference Fischer et al. (2006) pointed out that geographical distance has a very significant and substantial impact on knowledge spillovers. Knowledge flow among internal members of a region is simpler than that across regions. In addition, inter-regional knowledge flow occurs most frequently among regions which are close to each other in technology space.

We hold that the theory of “regional division of labor,” “interdependence,” and “competition and cooperation” can be introduced to explain the mechanism of spatial interaction in SoFs.

**Analyzing the mechanism based on “regional division of labor theory”**

The theory of “regional division of labor” includes “absolute advantage theory” (Smith 1776), “comparative advantage

theory,” (Li 1962) and “factor endowment theory” (Zhang 2013).

The “absolute advantage theory” holds that any country or region will specialize in production according to absolutely advantageous production conditions suitable for certain products, so as to improve the utilization efficiency of resources, labor, and capital. The “comparative advantage theory” is an important expansion of the “absolute advantage theory.” It believed that as long as there are relative differences in production costs among countries or regions, there would be regional division of labor. In the case of other similar conditions, different price cost of the same commodity in different regions caused by the differences in the technology level and other aspects is an important factor that promotes international trade and determines the mode of trade. “Factor endowment theory” argues that the difference of factor ratio is the key reason for the regional difference of product comparative cost. After the perfection of Samuelson and others, “factor endowment theory” has replaced the “Ricardian model” to become a modern form of “comparative advantage theory” and an important part of modern western international trade theory (Guo 2013). According to the theory of “regional division of labor,” human economic activities are regional. The comparative advantages among different countries or regions are the foundation of benefit generation. Each region makes full use of its own resources and advantages, focuses on the development of advantageous industries with distinctive characteristics, and produces distinctive products and exchanges with others to obtain other products they need (Cai 2009).

The main forms of interaction among entities in SoFs are as follows: (1) the flow of goods and population; (2) financial and economic exchanges; (3) the flow of information and technologies. Whether or not an entity is willing to interact with another entity in SoFs, and how strong the interaction will be depend not only on the actual needs of both sides but also on their infrastructure construction levels and policy orientations. Economics hold that: (1) The root cause of the flow of materials among cities lies in the existence of division of labor. (2) The difference in income and welfare system is an important reason for population mobility. People tend to move from the regions with fewer employment opportunities, lower income levels, and imperfect social security systems to the regions with more employment opportunities, higher income levels and higher social security levels. (3) The occurrence of material flow, capital flow, and information flow are directly or indirectly governed by human wishes.

### Analyzing the mechanism based on “interdependence theory”

Richard Cooper is the first economist to study “interdependence” in theory. He defines “interdependence” as “a sensitive response relationship between countries” economic development and international economic development” (Fan 2001). He believed that the transmission of economic interdependence is bidirectional. The economic development of a country or region will have an impact on the others.

In SoFs, the existence of interdependence increases the probability of spatial interaction, and contributes to the effective flow of element flows among countries or regions. For example, the oil-rich Middle East nations have become the main suppliers of many other countries. The stability of the situation in the Middle East has a direct impact on the oil price of the world, thus affecting the production and living costs of people. On the other hand, capital injection from other countries is the main economic income source of the Middle East. Oil production regions and consuming regions are interdependent and indispensable to each other, which ensure the continuous flow of material and capital. As another example, supposing that region *A* has extremely abundant coal resources, but its population is small, and lacks of mining technologies and equipment, while region *B* has developed economy, powerful comprehensive competitiveness, and a large demand for coal resources. Under this assumption, it is highly likely to trigger the flow of population (labor), information, technologies, capital, and material between these two regions.

When both *A* and *B* have the “resources” needed by each other, the element flows are most likely to flow directly or indirectly between them. The stability and long-term of the dependency relationship determines the intensity and sustainability of the flow of related element flows. If one side’s dependence on the other is changed, it will inevitably affect the flow intensity or flow frequency of the related elements. In extreme cases, it may even lead to dependency flee, namely, one side’s dependence on the other will disappear. In addition, the intensity of dependence on each other cannot be exactly the same. The side with less dependence has more initiative during the process of interaction and more control over the flow process.

### Analyzing the mechanism based on “competition and cooperation theory”

Bleeke and Ernst are the main representatives of “competition and cooperation theory.” They believed that for most of

the global enterprises, the era of beggar-thy-neighbor competition has ended. Competing enterprises can selectively share or exchange control rights, capital, costs, information, technologies, and market access opportunities with their rivals and partners in order to create maximum value for customers and shareholders (Bleecker and Ernst 2000). Now, this theory has become a new theory of enterprise management.

The literatures (Taylor 1975; Watts 1983), and Dicken (1986) have proposed the classic growth patterns of enterprise spatial successively. Under the background of global economic integration and diversification, enterprises constantly optimize and adjust their organizational structures, development planning, and strategic spatial layout. In the adjustment process of enterprise structures and strategic layouts, it is bound to lead to the generation and flow of element flows. Regional division of labor and trade is the inevitable product of social development. Regional economic cooperation has strengthened the inter-regional flow of production elements and the regional links. In this cooperation process, the barriers to the flow of element flows in SoFs have been eliminated intentionally or unintentionally. It will help the partners to achieve their own optimal allocations.

Taking the information flow as an example, participants with higher “information potential” in SoFs are usually dominate the advantageous positions in the process of competition with other entities. They usually have more initiative and decision power. In order to participate in the competition better, entities with lower “information potential” must try their best to improve their “information potential” by introducing high-end talents, new technologies, and so on. All participating entities compete with each other and develop together.

## Relevant researches on other aspects of SoFs

In addition to the study of SoFs’ concept and theory, the relevant studies mainly focus on the following two aspects: (1) studying specific problems in specific areas or specific fields based on the theory of SoFs or from the perspective of SoFs; (2) studying the spatial distribution pattern of some kinds of element flows in a specific area.

## Relevant researches from the perspective of SoFs

GaWC (Globalization and World Cities Study Group and Network) creatively characterized the internal and external linkages of world cities based on the location relationship between headquarters and branches of APS (Advanced Producer Services) (Taylor 2001). Reference Doel and Hubbard (2002) explored the strategic importance of key cities in the global economy, and focused on the efficacy

of city marketing and place promotion in boosting urban competitiveness. Based on the knowledge that we no longer live in a space of places, but in a global space of flows, it finally drew the conclusions as follows: (1) Successful city marketing relies on pursuing a specialized politics of flow rather than a place-based politics of competition. (2) City is not a localized place of economic competitiveness (i.e., a hub in this space of flows), but is a constellation that translates and mediates these flows through global space and networked time. (3) Cities can only enhance their competitiveness by recognizing that world-cityness is not determined by a city’s location in a pre-existing structure, but needs to be performed and worked at in a multiplicity of sites. In the process of network analysis on the world cities, the concept of SoFs was used. By studying the characteristics of the operation and flow of knowledge-intensive industries, they have broken through the difficulty of measuring the actual information flow and other functional flows among cities to a certain extent. Blatter applied Castells’s theory of SoFs on the political system and found that regional para-governance in Europe still follows the logic of SoPs, while SoFs appears as a complementary logic of community and institution building in North America (Blatter 2004). Polynet team applied the concept of SoFs on the eight mega-urban areas in Europe and extended GaWC’s methodology into inner urban areas (Pain and Hall 2006a). In their another work (Pain and Hall 2006b), they pointed out that the networked polycentric mega-city region has emerged as a new urban phenomenon. Developed around one or more cities of global status, it is characterized by a cluster of cities and towns, physically separate but intensively networked in a complex spatial division of labor. They introduced the concept of a mega-city region into the Polycentric Metropolis, analyzed its characteristics, examined the issues surrounding regional identities, and discussed policy ramifications and outcomes for infrastructure, transport systems and regulation. Furthermore, for the first time, they worked to show how businesses interrelate and communicate in geographical space — within each region, between them, and with the wider world. Their work is benefit to demonstrate the profound consequences for spatial planning and regional development in Europe and other similar urban regions of the world. What’s more, their research work has shown that the superiority of research from the perspective of SoFs lies in its ability to analyze urban systems and regional structures in depth from invisible functions, and then obtain new knowledge and discoveries. References Oosterveer (2006) and Bush and Oosterveer (2007) took the production and trade of Southern shrimp as an example to investigate the links between the flow of material commodities in SoPs and the transmission of information in SoFs. They devoted

to showing how innovative food governance arrangements appear in the context of global modernity, and claimed that the authority and power in such arrangements are shifting away from national governments and towards producers, processors, traders and consumers along the supply chain. This change makes the product or food and capital flow smoothly and widely. Furthermore, they pointed out that private arrangements allow consumer to become actively involved in global food governance in different degrees of intensity, and link them to their everyday practices of food consumption (buying, preparing and eating food). By combining SoFs theory and other theoretical methods related to advanced production services and financial geography, Sokol explored the “location structure” of financial services in economic geography and its impact on unbalanced regional development in Europe (Sokol 2007). Reference Sinn (2008) focused on the causes of the formation of Hong Kong’s SoFs. It pointed out that Hong Kong is an effective SoFs not only because of its geographical openness but also because of the freedom, openness, and security of the mobile environment created by various factors. Weinstock (2013a,2013b) identified “sentience,” or the ability to be aware, as the primary driver of innovation in the urban environment; as the extended “nervous system” of a city develops the potential to sense changes in the city’s flows, and in its internal and external environments. They thought that the evolution and development of the urban systems of an individual city are accelerated or constrained by the flows between cities across the global network. As the networks evolve, new dynamics emerge within individual and linked cities, and the inherited hierarchies of spatial distribution, the relative sizes of urban elements and growth patterns have begun to change accordingly. Further, they believed that the future city is fully intelligent. Its spatial patterns are culturally appropriate to its citizens, and it adapts itself to the fluctuations of its flows, and to the emergent phenomena of its cultural practices by expansions, contractions and re-configurations of its infrastructural systems, its spatial patterns and the morphology of its architecture. Based on detailed employment and telecommunications usage data in the southeastern United Kingdom, reference Reades and Smith (2014) adopted the idea of SoFs to establish a global sector-to-sector profile at the regional scale of megalopolis. Reference Rusta (2017) pointed out that intensive urbanization and large-scale growth are creating the new social, political, and economic dynamics. Urban sociology was facing the problem of explaining these innovations with the old paradigm. Therefore, he tried to update the concept of urban from the perspective of SoFs, and draw the conclusion that under the new conditions, urban perception can be understood as SoFs that creating the new forms of global network and interaction.

Reference Mao and Cao (2009) analyzed the flow mechanism of industrial transfer from the perspective of SoFs, and designed an intensity model of industrial transfer flow based on the gravity model. Then the model was used for calculating the trend of industrial transfer from southern Jiangsu to northern Jiangsu. By analyzing the urbanization process of the Pearl River Delta since the reform and opening up, reference Cen et al. (2013) found that the urbanization of the Pearl River Delta is a local urbanization with the characteristics of SoFs. Reference Ye (2013) studied the space of Shenyang city from the perspective of SoFs, and fully confirmed that SoFs is real. Combining with the characteristics of SoFs, it thought that from the perspective of SoFs, the main contents of studying urban spatial structure should include the analysis of spatial network structure and dominant factors, the measurement of each element flow, and the discussion of some other core issues. Reference Chen and Xiu (2014) studied the urban network in Northeast China also from the perspective of SoFs. Based on the distribution data of tourist attractions, reference Yu et al. (2015) analyzed the spatial structure and node hierarchy of Heilongjiang Province’s urban tourism network. Reference Ma (2017) explored the functional spatial relationship of urban agglomerations from the perspective of SoFs. It advocated the use of a variety of flow structures and flow forms to infer or analogize the functional relationship between the major functional nodes within urban agglomerations. Reference Wang et al. (2017) regarded Taobao Village as a SoFs which integrating information network and geographical space, and absorbing population flow, material flow, capital flow, technology flow and so on. It also held that Taobao Village is not only influenced by SoFs but also responds to the geographical space. Meanwhile, Taobao Village overflows from SoFs to influence the surrounding external space.

### **Research on the spatial pattern of related element flows in SoFs**

Apart from the researches on the concept or theory of SoFs and the related researches from SoFs perspective, other researches about SoFs mainly focus on the spatial pattern of some element flows within a specific region.

SoFs contains a variety of element flows, such as population flow, material flow, capital flow, and information flow. These flows interact with each other and stimulate the evolution and development of SoFs. With the reason that capital flows are tend to be attached to other flows, there are not many researches on capital flows alone. In terms of the specific research content, there are not only the researches on the spatial pattern of single flow (such as the study on the spatial pattern of population flow (Dewdney 1991; Bruijn and Dijk 2003; Liu et al. 2003; Hosegood et al. 2005; Lin

et al. 2005; Newson 2005; Lan et al. 2007; Yang et al. 2008; Wang et al. 2011; Gray and Mueller 2012a; 2012b), material flow (Xie and Li 2005; Yujuan 2008; Yujuan and Xiaoshu 2012; Jiang and Shi 2015; Heitz and Beziat 2016; Wen et al. 2017), and information flow (Mitchelson and Wheeler 1994; Grubestic and O’Kelly 2004; Liang 2009; Chen et al. 2012; Li 2015; Ningning et al. 2016) but also that of various types of flows and their interactions (Ningning et al. 2016).

Based on the relevant research literatures collected in this paper, we find the following: (1) At present, the literature quantity of population flow and its spatial pattern is far more than that of the other element flows. The literature quantity of material and information flow are in the second and third places, respectively. (2) The literature quantity of information flow and its pattern is still relatively small. The main reason for this phenomenon is that data related with information flow (such as the access data of websites, users’ relationships in a social networks, and mobile communication data) are difficult to obtain unless you work with their owners (business or government departments). Crawler technology is an alternative choice to obtain some experimental data related to information flow. The limitation is that it can only crawl the information published on owners’ specified websites. However, the quantity has increased rapidly in recent years.

## Conclusion and discussion

Currently, the regional space has been transformed from SoPs to a new type of space interwoven and blended by SoFs and SoPs. SoFs can break through the limitation of time and space. Its influence on regional spatial organization pattern is deepening. To a certain extent, it is guiding the formation and development of future regional spatial pattern. After introducing the formation and development of the concept of SoFs, this paper focuses on the relevant theories and spatial interaction mechanisms of SoFs. The research contents of this paper mainly include (1) elaborating the concepts of SoFs; (2) exploring the constitute elements of SoFs; (3) analyzing the correlation and comparison between SoFs and SoPs; (4) studying the interaction mechanism of SoFs; (5) introducing relevant researches on other aspects of SoFs. Our main conclusions are shown as follows:

- *SoFs is the product catalyzed by the development of ITs and economic globalization.* The core components of SoFs not only includes the various element flows and their carriers but also includes the entities who participating in the flow process. “Location,” “distance,” and “direction” not only are the three
- elements of traditional space but also are reflected in SoFS.
- *We are now in a new type of space with the coexistence of SoFs and SoPs.* These two kinds of spaces influence on each other and depend on each other. But what can not be ignored is that the influence from SoFs to SoPs is becoming deeper and wider. More and more activities have been shifted from SoPs to SoFs.
- *There is a variety of different types of flows in SoFs.* Although their functions are different, they are closely related to each other. It should be noted that information flow is playing a guiding role in the development of SoFs. Information flow can guide, regulate, and manage the flow of other element flows so as to realize the effective allocation.
- *The probability, frequency, and intensity of interaction among entities in SoFs are influenced by many factors, such as their subjective wills, policy directions, and some objective forces.* The relationships among entities are complicated, because there is not only cooperation but also competition. It is needed to point out that “information potentials” is a very important factor which greatly determine the positions and competitive powers of entities in economic exchange activities.

The coexistence of SoFs and SoPs has become a fact. By reviewing the current research work, we can find that more and more scholars tend to study the regional mobility and spatial pattern differences of some specific factors. However, to better understand and analyze the relationship between SoFs and SoPs more accurate, we think we should focus on the following aspects in the future: (1) exploring the mapping relationship between entities in SoFs and that in SoPs; (2) constructing mathematical models to carry out quantitative analysis on the influence from one kind of element flow to the others, the development potential of single entity, the interaction forces among entities, and the developmental maturity of the whole space.

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## Declarations

**Conflict of interest** The authors declare that they have no competing interests.

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