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Introduction

1.1 Collaboration and Collaboration Systems

It is a complex world. In a complex world, there are many problems for people to solve. To solve a problem, we need to establish the concepts, conduct abstraction to grasp the key points of the problem, design a model for the problem, provide a solution, and, finally, apply the solutions in the real world to verify whether the solution is acceptable. Albeit there are many simple problems that can be solved without much effort, researchers are only interested in complex problems. We should first clarify what a complex problem is.

To understand whether a problem is complex or not, we can simply check whether the problem can be formalized using symbols, formulas, equations, or other formal languages, where symbols have unique meanings. We can be assured that if a problem has not yet been formalized, it is a complex problem. On the other hand, if a problem can be formalized but the process to solve it has exponential complexity, it is also a complex problem. Under these criteria, collaboration is a complex problem.

We must admit that the research on collaboration is still in the stage of "infancy" (Miller-Stevens et al. 2016; Morris and Miller-Stevens 2016). The evidence to assert this claim derives from the following facts: (i) there is not a well-accepted definition to the term "collaboration"; (ii) there is not a well-accepted model to completely specify a collaboration system; and (iii) there is even no well-established methodology that can be applied to conduct collaboration in specific fields, e.g. health care or manufacturing.

This book is a first attempt from the systems engineering's viewpoint to kick off the investigation of collaboration and collaboration systems. This book aims to study collaboration, collaboration systems, and complex systems with the support of the model Environments – Classes, Agents, Roles, Groups, and Objects (E-CARGO) and the Role-Based Collaboration (RBC) (Zhu and Zhou 2006b) methodology.

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1.1.1 Collaboration

Collaboration is a polymorphic word. It has many different meanings depending on different viewpoints and contexts. In the 1980s, Gray attempted to define "collaboration" in public administration as "the pool of appreciations and/or tangible resources, e.g. information, money, labor, etc., by two or more stakeholders, to solve a set of problems which neither can solve individually" (Gray 1985, p. 912). Many researchers have defined collaboration very differently since then (Gray 1989; Thomson 2001; Thomson and Perry 2006). Thomson states that "collaboration is a process in which autonomous actors interact through formal and informal negotiation, jointly creating rules and structures governing their relationships and ways to act or decide on the issues that brought them together; it is a process involving shared norms and mutually beneficial interactions" (Thomson 2001). In fact, even Gray's definition has changed over time. In Gray's 1989 paper, Gray redefined collaboration as something that "transforms adversarial interaction into a mutual search for information and for solutions that allow all those participating to ensure that their interests are represented" (Gray 1989, p. 7).

Collaboration is started when all the participants bring something to the table (expertise, money, ability to grant permission), and put their belongings on the table (Thomson and Perry 2006). Collaboration ends when all the parties agree that the result is satisfied (success) or the collaboration cannot continue anymore (failure).

We believe that collaboration is a joint effort of many (>1) people to accomplish a designated task. It is also a problem-solving process that involves many (>1) different problem solvers (Hsieh and O'Neil Jr. 2002).

Definition 1.1 A *team* is a well-organized group of participants that work together to achieve common goals.

Definition 1.2 *Collaboration* is a joint effort to form a team.

To understand these definitions, we need to first realize that collaboration is a joint effort from a group of people, not a job for one person. That is, collaboration requires participants to share, communicate, and interact amongst themselves. Secondly, collaboration needs to set a goal when collaboration starts, i.e., collaboration must produce an artifact, accomplish a task or provide a result. Thirdly, collaboration includes more than one participant, which can be a device, a computer system, a person, an organization, or even a country. Therefore, we can view collaboration as a complex system (Section 1.7).

Collaboration, as a research field, has all the properties of a field that demands investigation:

1) Collaboration is necessary. From Figure 1.1 (UOPX news 2013), it is reported that seven in ten people have worked in a dysfunctional team during their

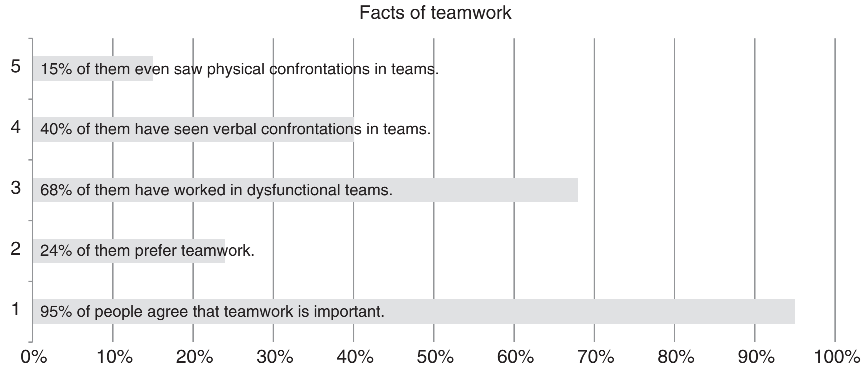

Figure 1.1 How important is teamwork? (ClassesandCareers.com).

lifetime (Item 3). Furthermore, collaboration was necessary for human survival in early human history. Early primitives had to collaborate to build shelters to protect themselves from natural disasters. They had to collaborate to defend themselves from attacks by ferocious animals, such as wolves, tigers, and lions. They collaborated to kill animals to obtain enough food. Therefore, collaboration is a fundamental activity of the human world. No one lives completely alone. People collaborate when a single person cannot accomplish a complex or difficult task, or if a single person can complete a task but it is not economical to do so. For example, to move a piano into a house from the outside is an impossible task for one person to accomplish manually but not very hard for four people to work together. Similarly, people can make tofu dishes in a restaurant, but it is too costly for them to make raw tofu by themselves. By collaborating with a local grocery store to purchase raw tofu, they save considerable time and effort while increasing profit.

2) Collaboration is complex and challenging. It requires many elements and involves a variety of combinatorics. For example, if a team has m members, the number of one-to-one connections between them is $\binom{m}{2} = m!/[2! \times (m-2)!] = m \times (m-1)/2$; the numbers of subgroups of 3 members is $\binom{m}{3}$, ... Therefore, the complexity of collaboration quickly becomes the exponential if we do not carefully organize.
3) Collaboration is interesting. It is fun to investigate the properties of collaboration. It provides researchers with many opportunities to satisfy their curiosities. The intermediate investigation results may be frustrating, surprising, and even exciting. Many collaboration problems may seem bewildering at the beginning. However, after sufficient effort, thinking, reasoning, and experiments are

applied, exciting results may be unveiled. Such a process is similar to the aesthetic appreciation process, i.e. the result of an investigation rewards a feeling similar to sensing the beauty of art.

4) Collaboration is beneficial. Not only is the result of collaboration beneficial, but also is the collaboration process. Many methodologies, algorithms, and technologies developed from the research of collaboration make a fortune for people in different fields. Continuous efforts in collaboration research contribute to both the research community and industries. The following chapters will provide more concrete cases.

Collaboration requires people in a group to fulfill their obligations and respect the rights of others. To collaborate, people generally participate in a group or organization. The related parties must establish common goals by negotiation, divide the whole task into subtasks, distribute subtasks to related parties, and, finally, integrate all complete subtasks to a unified result.

Examining the components of collaboration and the type of interaction between them, collaboration can be classified into the following categories:

- *Natural Collaboration* occurs among people/organizations who are members of a team (Figure 1.2). Looking at Figure 1.2, we can observe how complex

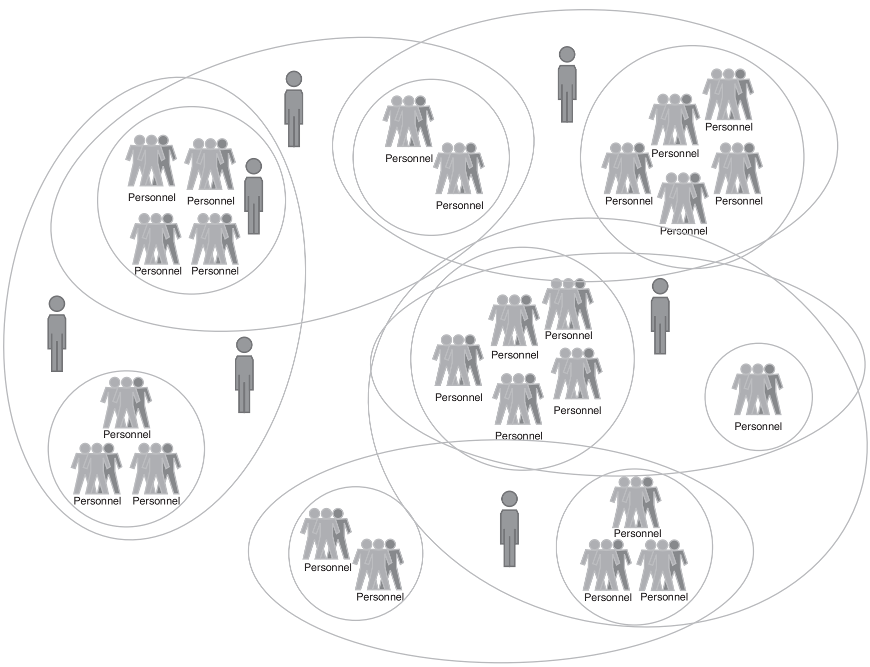

Figure 1.2 Natural collaboration.

collaboration can be. Furthermore, the overlapping and interleaving of teams make collaboration even more complex. Figure 1.2 presents three types of participants: the groups, the small groups, and the manager of a group. We may take the single-large-person icon as a manager, the three-person icon as a small group, and a circle-including-person icons as a group. Please note that, in Figure 1.2, the sharing among the participants is hidden. Most of the problems in natural collaboration arise from the difficulties in sharing resources (Wondolleck and Yaffee 2000) such as knowledge, information, and technologies.

- *Computer-Supported Cooperative Work (CSCW)* (Grudin 1994) is a research topic that mainly focuses on innovations to support collaboration among people through computer systems (Figure 1.3). From Figure 1.3, we observe that people are collaborating through the use of computers. Note that we can include any equipment that facilitates collaborations, e.g. all the devices and equipment presented in Figure 1.4 about Human–Computer/Machine Interaction. Figure 1.3 clearly shows that the CSCW users are sharing the cloud, which is the most important resource in CSCW. If the cloud had unlimited storage capacity and unlimited communication bandwidth, CSCW technology would be easy to implement.

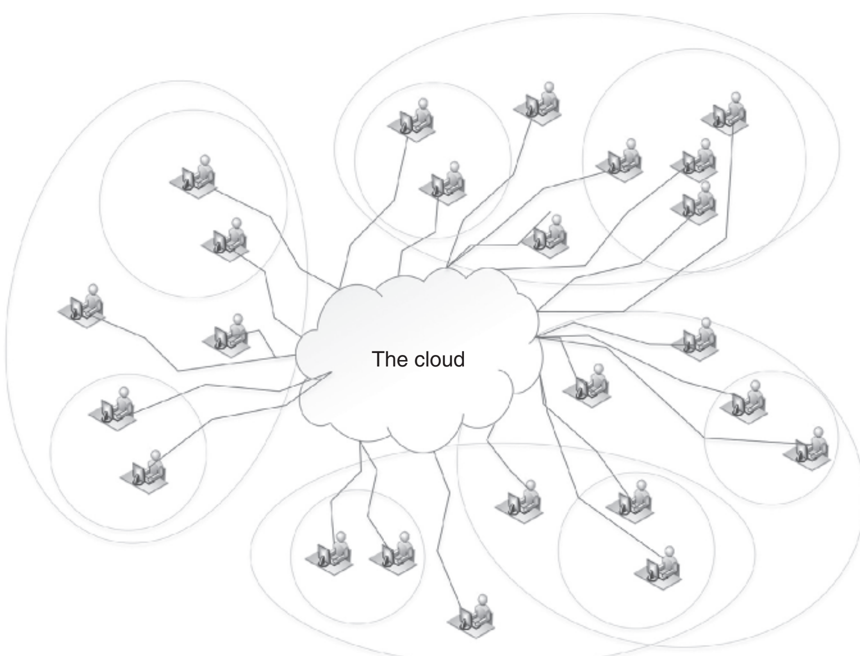

Figure 1.3 Computer-supported cooperative work (CSCW).

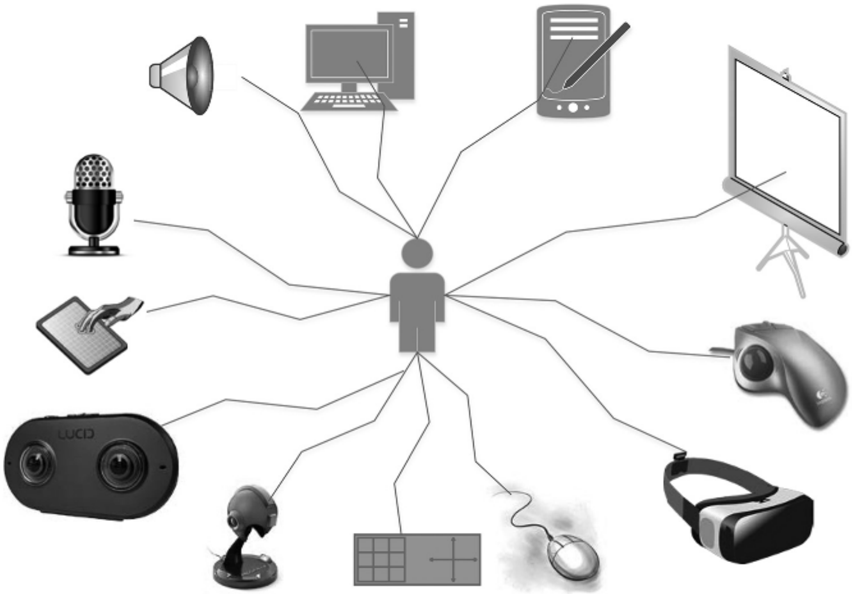

Figure 1.4 Human–computer/machine interaction (HCI/HMI).

- *Human–Computer Interaction (HCI)* (Dix et al. 2003, Preece et al. 1994) *or Human Machine Interaction (HMI)* (Böhmea et al. 2003) is a research field that mainly investigates how to support collaboration between a human and a computer/machine system (Figure 1.4). The aim of HCI/HMI research is to provide more comfortable ways for human users to utilize computers and machines. The challenge for HCI/HMI is understanding the natural interaction ways among human beings and making computers and machines more humanized. Another exciting field in HCI/HMI is augmented interaction (Rekimoto and Nagao 1995), which supports supplementary ways for people to interact with computers and machines other than natural interaction ways. Brain–Machine Interaction (Ramos-Murguialday et al. 2013) is also a hot topic in the HCI/HMI field seeking to help people interact with machines directly through brain neural signals.
- *A distributed system* (Coulouris et al. 2011, Tanenbaum, and van Steen 2016) is a computer system that supports collaboration among computer systems (Figure 1.5), which have their own processors and main memories. The aim of distributed systems' research is to provide more highly available and high-performance computing that acts as though a user is only operating one computer system, i.e. all the components of the distributed system are transparent for the users. Therefore, the cloud metaphor is a very appropriate analogy for

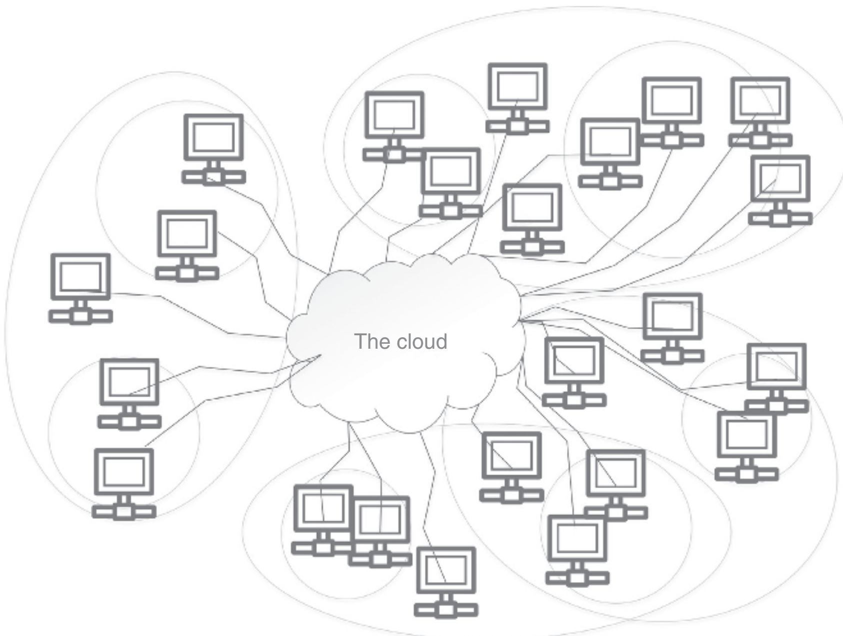

Figure 1.5 Distributed systems.

a distributed system. The challenge of distributed systems lies in providing high processing speed, sufficient communication bandwidth, and a large, safe, stable, and secure storage space for cloud clients.

- *Robot collaboration* is a new topic of research with the development of robot technologies. The goal of this form of collaboration is to form a robot team to accomplish a task that cannot be completed by a single robot. After robots possess human-like abilities, it will be possible to develop a robot team to collaborate to accomplish complex tasks. Figure 1.6 presents the possibility of different robots/agents, groups, and group leaders in collaboration. In robot collaboration, the current major challenge is ensuring that robots possess the necessary abilities for collaboration (Rekleitis et al. 2001), autonomously make decisions, directly sense each other and avoid nearby obstacles. After such robots are built, the methodologies and technologies discussed in this book may be directly applied.

Collaboration can also be classified into such categories: *Mandated collaboration* (Buppert 2010; McNamara 2016) and *voluntary collaboration* (Vella et al. 2016). By mandated collaboration, we mean that the participants are not willing to collaborate but have to do so. On the other hand, voluntary collaboration means the opposite, i.e. the participants are willing to collaborate.

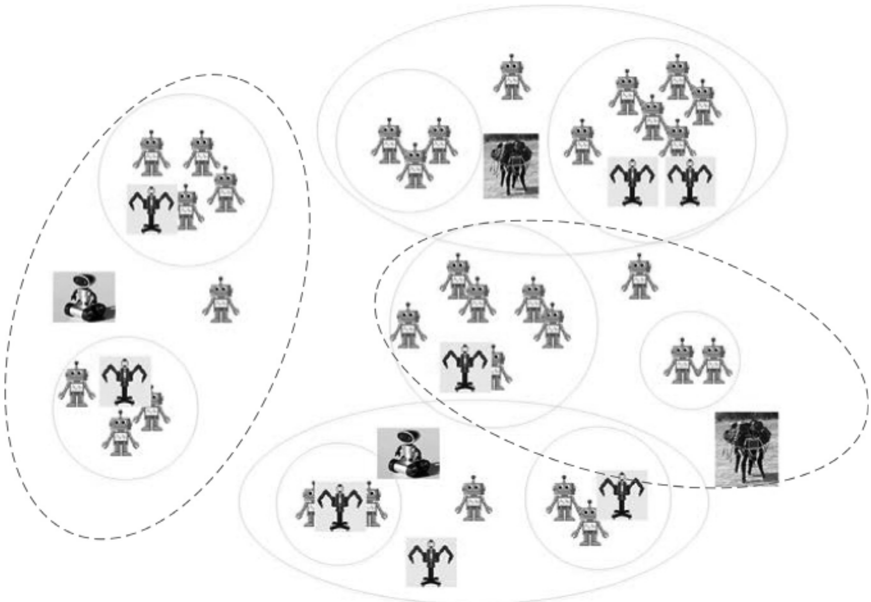

Figure 1.6 Robot collaboration.

For voluntary collaboration, all the participants have the same goal to make the collaboration a success. Therefore, they may put the team's benefits and interests above their individual benefits. However, in mandated collaboration, participants do not hope to collaborate and therefore may be more interested in their individual benefits as opposed to the team's.

An interesting phenomenon is that the difference between mandated and voluntary collaborations is equivocal, that is, we may say that most collaborations are necessary and mandated.

For example, a hospital may wish to investigate a medical technology by itself and requests funds from the government. However, the government requires that at least five hospitals be organized as a team to apply for the government funds. Is this a mandated or voluntary collaboration? Most will answer "mandated collaboration." Another example is a company that hopes to develop a new technology, which is supposed to have a large future market. However, the company lacks key resources, such as technology, financial support, and working spaces. It has to contact several companies to meet the requirements of this project. As a result, it has to yield parts of the future benefits to its collaborators. Is this mandated collaboration or voluntary collaboration? This is also mandated collaboration.

Do we have examples for voluntary collaboration? Yes, we can say that CSCW platform users are conducting voluntary collaboration because they are remotely located and they use such platforms in hope of collaborating. They are intending to collaborate. The discussion in a saloon bar can be taken as a voluntary collaboration because all the participants are voluntary.

"Cooperation" and "coordination" are normally used to describe activities similar to "collaboration." In this book, we will clarify these concepts by formal specifications. We believe that collaboration is composed of coordination and cooperation. The collaboration represents a broader scope than coordination and cooperation. Collaboration involves the initiation, planning, and administration of a team. Cooperation deals with detailed interactions among the members of a team. Coordination deals with the management issues of cooperation among team members in a specific scope other than that of collaboration.

Gray (1989) states that "even though both cooperation and coordination may occur as part of the early process of collaboration, collaboration represents a longer-term-integrated process through which parties who see different aspects of a problem ..., constructively explore their differences ..., and search for solutions that go beyond their own limited visions and implement those solutions jointly."

In her interviews with public agency directors between 1995 and 2000, Thomson (2001) found that, in contrast to the ease with which they define cooperation, agency directors frequently resort to using metaphors to describe collaboration, such as "stepping into other people's shoes," "the combination of hydrogen and oxygen atoms to form water," and "combining yellow and blue circles to form a larger green circle."

Collaboration can be simple or complex. Individual components can accomplish a difficult task by simple collaboration, e.g. one person cannot carry and transport a heavy log manually, but many people together can do it by simply lifting and moving at the same time and pace. One grain of sand can do nothing but tons of sand together can form land and block flooding. This is typical and simple collaboration, i.e. collaboration only by getting together to do something at the same time. Simple collaboration can create considerable results. One participant may not present any special characteristics. However, if there are enough participants, a special property will be produced, i.e. emergence. For example, we do not feel humid from only one molecule of water (H_2O), but we will feel dampness if the humidity reaches 100%, which involves numerous molecules of water. A drop of water can accomplish nothing in most cases, but a bottle of water can help a lot when a person is thirsty and a large quantity of water may form flooding and even destroy lives and buildings. Simple collaboration explains the phenomenon of emergence, which strongly supports the philosophic law, "quantity change may lead to quality change."

A more common type of collaboration is complex collaboration, i.e. complex components get together to accomplish a complex task. Complex collaboration is the major concern of this book. However, the developed models, methodologies, and algorithms discussed in this book can also be used for investigating simple collaboration.

1.1.2 Collaboration Systems

After we discuss collaboration, we need to clarify the terms of "collaboration systems" and "collaborative systems." Conventionally, collaborative systems and collaboration systems have trivial differences. They are often applied interchangeably in different contexts. From our long-term research, we gradually replace the term "collaborative systems" with "collaboration systems." The reason is subtle and seems arbitrary. However, such a choice implies a deep understanding of the nature of collaboration theory and technologies. Therefore, in this book, we differentiate between "collaboration systems" and "collaborative systems."

Definition 1.3 *Collaborative systems* are computer-based systems that assist human users in collaborating remotely with the assumption that the components of the system are collaborative. That is to say, the components of the system, or the participants of collaboration, intend to collaborate, but not the opposite.

For example, we can take Zoom, Google Meet, Cisco Webex, and Microsoft Teams as collaborative systems.

Definition 1.4 *Collaboration systems* are computer-based tools or platforms that support human users to form teams locally or remotely. The users of such systems assume that they may not only collaborate but also compete. Such a system does not require that participants have to be at a distance.

Collaboration systems are the ideal goal of researchers and practitioners of collaboration. That is why we cannot present such examples now. However, we do have tools or platforms that partially meet the requirement of collaboration systems. For example, all the above-mentioned collaborative systems provide partial functions of a collaboration system.

Collaboration tools or platforms enable individuals to share their ideas and talents with collaborators so that a task can be finished efficiently and effectively. This means that the system may include components that do not intend to collaborate or are pushed to collaborate.

We may simply say that collaborative systems are for voluntary collaboration and collaboration systems are for both mandated and voluntary collaboration. Technically, collaboration systems are more complex and difficult than collaborative systems because the former needs to support mandated collaboration and the latter mainly pertain to voluntary collaboration.

Note that a collaboration system supports all the participants to collaborate. It also sets policies to restrain the participants' behavior and establishes criteria to evaluate participants' eligibility to remain in the system. Therefore, we need to consider the problems of cooperation, coordination, competition, and conflict.

We also need to consider the culture or style when organizing collaboration, i.e. individualism or collectivism.

Both collaboration and collaborative systems can also be called collaboration support systems (Cabri et al. 2006).

1.2 Collaboration as "Divide and Conquer"

The fundamental method of software engineering in meeting the challenge of the software crisis in the 1970s was "*divide and conquer*," which is also the basic method for complex problem solving. Therefore, "*divide and conquer*" is taken as the fundamental method used in this book for solving problems in collaboration. In complex problem solving, there are many related concepts that we need to clarify because these concepts help establish a well-accepted methodology and a well-defined model.

In daily life, we often try to obtain our own abstract view, or model, of a problem before a solution is found. In dealing with complex situations, we also need to extract the most important elements. These extractions are an activity of abstraction.

Definition 1.5 A *model* is a template for creating instances and a skeleton to reflect the structure of an object.

A model defines an abstract view for a problem that focuses on only the characteristics related to the problem. From object orientation, a model normally defines data and operations on the data. It is also a simplified representation of a complex reality. This representation is usually for the purpose of understanding reality and containing all the features of reality that are necessary for the task or problem (Zhu and Zhou 2006a).

Definition 1.6 *Integration* is a process used to collect all the related entities in the scope of the stakeholders.

For example, collecting data is a process of integration.

Definition 1.7 *Abstraction* is a process used to understand a problem by separating necessary details from unnecessary ones. The process of modeling is a type of abstraction.

Abstraction is extracting, forgetting, discarding, identifying, and structuring. Informally, abstraction means to "drop" certain "nonessential" features from a representation. We need to be careful about this process because it implies "forgetting." However, this "forgetting" is used to help "remember." In other words, if we are now in an abstraction process, we can say, "don't bother me with the details." This statement has led to the scientific term "information hiding."

Definition 1.8 *Information hiding* is a process used to discard the details of the things in consideration and is also a way to make it impossible for anybody who is not “authorized” to access the hidden details.

At first, information hiding is a purposeful omission of details in the development of an abstract representation. In traditional Chinese education, teachers teach students that there are two phases to read a book. The first phase is to read the book from thick to thin and the second one is to read the book from thin to thick. The meaning of “from thick to thin” is actually an abstraction by information hiding. For example, writing a summary of a book occurs in this step. The next phase of “from thin to thick” means extending by adding details based on the abstraction obtained from the first phase. For example, retelling the details of the book.

From the viewpoint of object orientation, abstraction falls into two general categories: data abstraction and control abstraction. Data abstraction concerns the properties of data, such as numbers, character strings, or other complex entities that are the subjects of computation. This often produces data structures. When we are using a data type, we specify what we can do with this type, but we abstract away how to do it with a given programming language.

Control abstraction deals with the properties of a control transfer, i.e. the modification of the execution path of a program based on the situation at hand. Control abstraction usually produces algorithms. When we are writing a function, we can put calls to other auxiliary functions into it. We specify what these auxiliary functions do, but we abstract away how they do it.

If a problem is too complex to solve or if a thing is too complex to understand and remember, we need to make an abstraction of it. We can view abstraction as a tool to know, create, and understand complex things. For example, a world map is an abstraction of the earth and a provincial map of Ontario is an abstraction of the Province of Ontario. A book of Canada is, in fact, an abstraction of Canada from the viewpoint of the book’s authors. Therefore, we can conclude that abstraction has different directions based on different aims and uses.

On the other hand, abstraction is a general methodology to know and study the world and knowledge. When we have many concrete objects to control, we generally remember their common properties and specialties. This is an abstraction process. The result of this process is an abstract concept. For example, dog, horse, and people are abstract concepts, and big data needs abstraction to be useful and valuable.

From these two points of view, we can conclude that “abstraction is the purposeful suppression, or hiding, of some details of a process or artifact, in order to bring out more clearly other aspects, details, or structure” (Budd 2001). Through abstraction, we can understand other relevant concepts, such as information hiding. For example, all the textbooks are abstractions of relevant knowledge.

Definition 1.9 *Modeling* is a process of abstraction, i.e. the process of focusing on those features that are essential for the problem at hand and ignoring those that are not.

Definition 1.10 *Classification* is a general methodology that puts things with similar properties together and differentiates things that have different properties.

Classification is applied in many domains of human lives. Some researchers even categorize classification as a form of abstraction (Budd 2001). Generally speaking, that is true. But in programming, classification and abstraction are different because they concentrate on different aspects of problem solving. An object-oriented system takes classification as a key mechanism to arrange elements in programming.

The “divide” phase in “divide and conquer” is accomplished when each component can be assigned to a single participant.

During the “conquer” phase, we need to understand the following concepts:

Definition 1.11 *Communication*, in general, is the action of exchanging information among different people or autonomous entities.

Definition 1.12 *A connection* is a relationship in which a person, thing, or idea is associated with something else. It is the foundation of communication (Zhu 2008).

Definition 1.13 *An interface* is a medium for two entities to accomplish connection, i.e. a common system of symbols, signs, frameworks, patterns, or behaviors.

Definition 1.14 *Interaction* is a mutual and reciprocal action or influence. It is a situation where two or more participants or things communicate or react to each other (Fischer 2001; Zhu and Hou 2011).

Definition 1.15 *Coordination* is the process of organizing participants so that they work together properly and form a harmonious, functioning part of a team (Nwan et al. 1996; Hou et al. 2014, p.58–59).

Definition 1.16 *Cooperation* is a process in which multiple participants work together in parallel while interacting with each other to obtain the required resources or services by coordination (Hou et al. 2014, p.58–59).

From the above definitions, we differentiate cooperation from coordination and collaboration to clarify the problems of collaboration. Figure 1.7 uses the composition relation, i.e. a concept in a larger circle is composed of the concept in a smaller circle, to show that cooperation includes coordination; coordination needs interaction; interaction requires communication; communication is based on

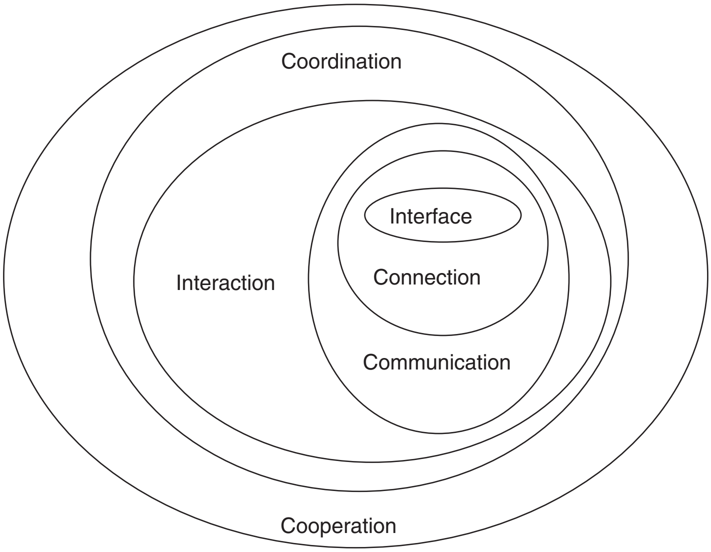

Figure 1.7 The relationships between the related terms.

the support of connections, and connections can be implemented with interfaces, which are foundations. Readers may ask, "where is collaboration?" The answer is that collaboration is composed of cooperation, which is categorized as "role-playing" in RBC (see Chapter 3) and "role-playing" is not the concentration of this book. Or, in other words, this book investigates all the related problems out of Figure 1.7 but aims to simplify the problems in Figure 1.7.

Note that the advocated methodology in this book is *Role-Based Collaboration* and we also propose an application of RBC to interaction, i.e. *Role-Based Interaction* (Zhu and Hou 2011). There may be a question: How do we conduct role-based cooperation, coordination, and communications? We have to admit that we have not yet accomplished solid and sufficient research on these aspects. There are still research potentials in these aspects. E-CARGO and other modeling methods in the subsequent chapters might also be applied in answering this question. Readers who are interested in this question are welcome to delve into related investigations.

1.3 Key Components of Collaboration

Collaboration, as a system, is composed of components and can be divided and conquered. However, collaboration is complex and not easy to divide. Few researchers have provided a well-accepted decomposition of collaboration. The following components of collaboration are proposed by the field of public administration (Mayer and Kenter 2016):

Communication: Each team member must communicate with each other. Such communication increases understanding. Good communication promotes collaboration and poor communication hinders it.

Consensus decision making: The team needs to take action in a consistent way. In collaboration, decision making may be individual, collective, local, and global. All decisions and decision steps should be in consensus. Discordances and conflicts may make a mess.

Roles: For participants to collaborate effectively, there should be different positions, or roles, available for the team members to take. Each member should play specific roles that match the member's interests, abilities, and skills.

Goals: Each collaboration should have a result, i.e. a product, a state, an achievement, or an accomplishment. Such a goal should be shared by all team members.

Leadership: A leader (Day et al. 2014; Goleman 1998) is a special role in a team. A leader needs to foster a sense of trust and loyalty in the team. The leader role requires the role player to possess a strong self-driven personality. The team should accomplish the task with the driving force of the leader.

Sharing: Sharing is essential to collaboration. It reflects the nature of collaboration (Section 1.4). Sharing includes resource sharing and view sharing. In collaboration, resources should be shared and administrated in an effective way so as to avoid conflicts among the team members. In collaboration, all the team members should share a common vision or view related to the goal.

Social capital: Social capital is a complicated factor that refers to the value of collaboration, which includes all the involved elements, the relationships among these elements, and the impact that these relationships have on the whole collaboration.

Social capital (Adler and Kwon 2002) can explain the achievement of collaboration, i.e. the improved performance of teams, the growth of enterprises, winning games, the successful products from a factory, the profit of an organization, or the evolution of communities. Social capital is considered the investment of resources with an expected return (Lin 2011).

Trust: Trust is a particular level of confidence for one person to assess that another person or group of people will perform a particular action before it is done (Dasgupta 1988; Gambetta 1988; Luhmann 2017; Ramchurn et al. 2004). Trust can be interpreted as both a property and a relationship. From the viewpoint of a property, trust is highly related to credibility, quality, reputations, reliability, validity, utility, robustness, and false-alarm rate.

From the relationship's viewpoint, trust can be set up, evolved, and broken up and trust can be divided into long-term and stable trust; transient trust; and the ways of how trust evolves across time. In collaboration, each team member should trust each other. The loss of trust may lead to a failure of collaboration.

In addition to the list above, we need to add one more essential component to collaboration.

Role players: participants or role players are essential components that cannot be ignored in collaboration. Without role players, there would be no collaboration. They are essential and necessary for collaboration. Different participants can both contribute to and create trouble in collaboration.

In this book, we will develop models and methodologies for collaboration. We believe that these models and methodologies will reflect the components of collaboration.

1.4 The Nature of Collaboration

Collaboration is like a "Man of a Thousand Faces." It is easy to tell the properties of it, e.g. Section 1.3, but it is difficult to explore its nature. To really understand collaboration, we need to delve into its nature. Following the idea of "divide and conquer," we will clarify the nature of collaboration.

We can describe natural collaboration as a class (Figure 1.8). When collaboration is started, we first encounter scattered *people*. All these people need to take responsibility and hold rights in order to contribute to the goal of the requested or designated task, i.e. playing *roles*. These two parts are essential attributes of collaboration. During a collaboration, people may bring in their physical and mental resources. All the participants need to *share* these pooled resources.

Such sharing can be done by *integrating* and *distributing* resources. That is, *sharing* is the essential activity of collaboration. Therefore, we believe that the nature of collaboration is that *People* play *Roles* by *Sharing*. In the narrowest sense, sharing refers to the joint or alternating use of inherently finite goods, such as a common pasture or a shared residence. We can restate that the nature of collaboration is a team of *participants* playing different *roles* by *sharing* the common goal and designated task of the team.

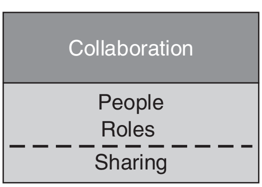

Figure 1.8 The nature of collaboration.

In collaboration, *sharing* is a highly abstract function of the collaboration class that includes everything related to collaboration. Sharing includes sharing the input, the process, and the output. Therefore, sharing can be categorized into responsibility sharing, view sharing, data sharing, information sharing, knowledge sharing, resource sharing, intelligence sharing, benefit sharing, and more. Each kind of sharing needs a nontrivial effort to ease collaboration.

For example, in CSCW, view sharing can be supported by "What You See is What I See" (WYSIWIS) technology. Data sharing, information sharing, knowledge sharing, resource sharing, and intelligence sharing can be supported by information technology. Benefit sharing means that collaboration concentrates on mutual benefit. Joining a team is better than being alone, i.e. if one can gain more than what they can gain by themselves, they are likely willing to participate in the collaboration.

Problems and challenges occur in sharing, i.e. synchronization, mutual exclusion, deadlock, information leaking, security, and conflicts. To avoid problems associated with sharing, we need the process of dividing and distributing. Well-done distribution can avoid problems or at least ease the problem solving. That is to say, sharing can be further divided into two major aspects: distribution and execution (Figure 1.9). In Figure 1.9, we use UML (Fowler et al. 2003) symbols, i.e. classes and compositions, to express their relationships. It is generally accepted that collaboration is composed of distribution and execution.

To facilitate distribution, we need the processes of integration, negotiation, specification, evaluation, and assignment. Integration is used to collect all the ideas and resources brought in by the participants. Negotiation means all the participants need to negotiate their common goals, benefits, resources, processes, and tasks. Specification means that all the negotiated entities must be specified by

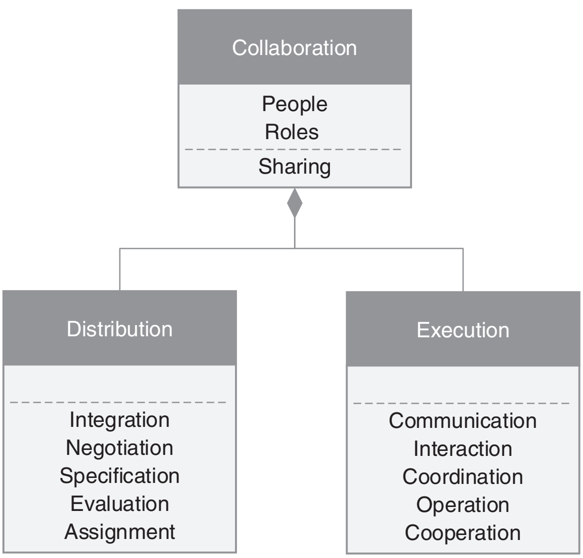

Figure 1.9 The two major parts of collaboration.

formalizations to avoid ambiguity and increase clarity. Evaluation is used to check all the requirements and the provisions and digitalize the matching degrees between the two. Assignment (Burkard et al. 2009) is used to couple the most suitable requirements to the required provisions from the viewpoint of collaboration but not any individual participant's viewpoint.

To conduct execution, we need the processes of communication, interaction, coordination, operation, and cooperation as defined in Section 1.2. We need to point out that the complexity of collaboration mainly comes from communication, interaction, coordination, and cooperation because of the sharing requirement. If the distribution is accomplished well enough, the execution will become less complex by that all the players concentrate on their individual operations. That is why this book's major contents concentrate on the models, algorithms, and methodologies to support distribution.

1.5 The Complexity of Collaboration

It is not very hard to assert that collaboration is complex because collaboration involves various dilemmas. These dilemmas may involve multiple participants and the participants may have shared interests but insufficient resources. They may dispute over the ways to solve a problem. They may have different degrees of skills and experiences. There might be inadequate administrative processes ready to deal with a challenge (Gray 1989; Poutanen 2016). Collaboration is complex because there are many things in the world and there are many connections between those things. In conventional thinking, collaboration is a complex skill that people need to learn, study, and practice for their whole lives.

The complexity of collaboration comes from the abundant interactions between team members. When we look at collaboration, our focus shifts from the individual components to the whole team. The complexity emerges as a result of the patterns of interactions between the components. Furthermore, the complexity also originates from the numerous ways of forming a group.

As we discussed in Section 1.1, we know that the number of undirected connections for a team of m members is $m \times (m-1)/2$. In one connection, we may conduct different interactions. If we introduce n to represent the average number of ways of interactions for each connection, the number of interactions is now $n \times m \times (m-1)/2$. Moreover, if we consider the connections between groups, then suppose we have p groups in a team of m members, the number of connections is now $m \times (m-1)/2 + p \times (p-1)/2$, which means we consider both connections between individuals and between groups. As for the number of ways to form a group, we have $\sum_{i=1}^{m-1} \binom{m}{i} = 2^{m-1} - 1\,(m > 1)$ ways for dividing the team into two groups.

The cases may be more complex if we consider the ways to divide the team into 3 groups with k_1, k_2, and k_3 members, $m = k_1 + k_2 + k_3$. The number of group formations is: $m!/(k_1!k_2!k_3!)$ (Brualdi 2008). If we continue, one may find that collaboration can be significantly more complex by introducing more different cases.

To overcome the complexity challenge of collaboration, we use the "divide and conquer" methodology to investigate the nature of collaboration as discussed in Section 1.4:

Collaboration = Distribution + Execution.

Distribution is to assign different tasks to the participants of collaboration, and execution then allows all the participants to concentrate on accomplishing their own tasks and they may need to cooperate with others through sharing, communications, interactions, and coordination.

Distribution has been investigated for decades as a complex problem (Burkard et al. 2009). Related terminologies include "assignment" and "scheduling." Distribution needs integration and division. From software engineering's viewpoint (Pressman 2014), "divide and conquer" is the fundamental approach to producing a high-quality software product. To manage task distribution, we must first divide the whole task of collaboration into subtasks. In many cases, it is very hard to divide a task into subtasks (see Section 1.7). Therefore, distribution is a complex problem.

Execution is complex due to the sharing, concurrency, and parallelism among the collaborating participants. From a computer systems' viewpoint, it is a multi-process and multi-thread execution. That is why we need to deal with the complexity of sharing, communications, interactions, coordination, and cooperation.

If people accept that game theory (Osborne and Rubinstein 1994) deals with complex problems in economies and societies, it is easy for them to accept that collaboration deals with complex problems because collaboration involves scenarios with multiplayer games.

Readers may find that after reading the following chapters, even though collaboration is made easier with the assistance of the proposed formalized methodologies, algorithms, and models, many problems in collaboration are still very complex.

1.6 Collectivism or Individualism

When we talk about natural collaboration, we cannot avoid the consideration of the participants' interests. We have to make a choice: collectivism or individualism.

Individualism emphasizes the individuals' interests and benefits. With individualism, participants act on their own judgments, keep and use the product of their own efforts, and pursue the choices they value. That is to say, the individual is sovereign and the fundamental unit of moral concern. Individualism emphasizes the moral worth of an individual. That is why investigators emphasize agents' individualism in developing multi-agent systems (Alonso 1999; O'Sullivan and Haklay 2000).

Individualism is reasonable (Biddle 2012), we can observe the world and people and immediately see different individuals. The individuals may be in groups (e.g. on a hockey team), but as individual people. People have their own bodies, minds, and lives. Groups are nothing more than individuals who have come together for some purpose.

Collaboration has many individual participants. Intuitive thought is that we need to consider individual participants' benefits when conducting sharing, i.e. we need to be fair in distribution. Here we have an important criterion, i.e. what we mean by *fairness*. We must admit that *fairness* does not simply mean that everybody shares the same amount of resources and tasks.

When we are thinking of collaboration, we need to accomplish the task designated to the team of people involved in the collaboration. Accomplishing the task is the top goal of the team. If the team accomplishes the task, every participant in the team will definitely obtain benefits. If the team fails, each member of the team will lose. If the team fails, fairness has no meaning for participants in the collaboration. Now, we need to shift our concern to collectivism.

Collectivism indicates a phenomenon in which collaboration is powered by the interest or benefit of the whole team. We believe that collectivism does not destroy all individuals' interests and benefits. Collectivism is to maximize the team's interest and benefit. When conducting collaboration, individual interests and benefits are second to the team's interest and benefit. If an individual's interest is in conflict with the team's, the individual should follow the regulation of the team to maximize the team's benefit. Such a choice may seem unfair to the individual in a short period. However, maximizing the team's benefit can make each individual feel fair for a long period due to adaptation, i.e. in the series of activities of collaboration, these individuals can be offered better shares by playing roles. An extreme solution to alleviate such a bad feeling is to allow the individuals to leave the team if the individuals feel that they are unfairly treated.

According to collectivism, one statement is "the group or society is the basic unit of moral concern and the individual is of value only insofar as they serve the group." That is why collectivism is not welcome in the western world in general (Biddle 2012).

Note that, in this book, we are discussing *collaboration*. We should advocate collectivism, at least during the period of collaboration. We definitely emphasize that the team is the only entity we care about during collaboration. Successful collaboration is for the team but not for individual participants as a starting point. However, individuals definitely gain from the successful collaboration by joining the team. For example, in the National Basketball Association (NBA) season, a basketball player will receive a significant remuneration after the team wins the final game, even though the initial goal of the team is to win a set of games without considering the individual players' interests.

Therefore, we encourage collectivism first and then consider individualism second. That is to say, in developing collaboration models, methodologies, algorithms, and structures, we are aiming at advocating collectivism first, and at the same time, also encouraging the investigation of those policies by considering individualism if possible (Zhu 2020).

Collaboration is a result of decision making. To determine whether we conduct collaboration may take different viewpoints:

From the viewpoint of individualism, we can use a simple formula (1.1) (Grasse and Ward 2016) to judge whether participant i chooses to join collaboration:

$$B_i \times P_s > C_i, \tag{1.1}$$

where B_i is the expected benefits in dollars for participant i, P_s is the success probability of collaboration, C_i is the cost in dollars paid by participant i, i.e. $C_i = T_i \times H_i$, and T_i is the time used by participant i and H_i is the hourly rate of participant i.

However, from the viewpoint of collectivism, we need to use formula (1.2) to judge whether to conduct collaboration:

$$B_t \times P_s > \sum_{i=0}^{m-1} C_i \tag{1.2}$$

where B_t is the expected benefit in dollars for the team.

For example, John, a software developer, expects to obtain \$100 000 (B_i) when the software development project successfully delivers and the probability of success (P_s) is 80%. If he needs to pay a total time (T_i) of 1000 hours in the project including meetings, coding, testing, and maintenance, and his current hourly rate (H_i) is \$60, he can easily decide to join the project because $C_i = \$60\,000$, and $B_i \times P_s = \$80\,000$. If he needs to pay 1400 hours, he will not. This is a decision decided by individualism.

On the other hand, Ann, the Chief Executive Officer (CEO) of a consulting company, expects to obtain the benefits of \$1M to sign a new contract. If she needs 10 employees in her company to work 1000 hours each, the average hourly rate of the employees is \$60, and the success probability is 80%. She would like to sign the contract. If she needs 15 employees, she would not. This is a decision decided by collectivism.

We believe that collaboration brings in benefits that will be shared by individual participants in the collaboration. Therefore, successful collaboration is a common goal for all participants. It is true that in some situations, maximizing the benefit of collaboration from the viewpoint of collectivism may be detrimental to the benefit of some individuals. However, we also believe that sharing the benefits obtained by successful collaboration may significantly alleviate an individual's losses caused by collectivism.

1.7 Collaboration and Complex Systems

1.7.1 What Are Complex Systems?

A complex system consists of numerous elements, which can function independently and may interact with each other. It is also defined as a system that cannot be easily decomposed into simpler subsystems. Complex systems have behaviors that are difficult to model due to the dependencies, competitions, relationships, or other types of interactions between their parts or between a given system and its environment. A system is complex if it has distinct properties that arise from the relationships among the components of the system. The properties of a complex system normally include nonlinearity, emergence, spontaneous order, adaptation, and feedback loops.

A complex system involves collaboration, at least at the level of distributed systems, i.e. the collaboration, cooperation, coordination, and interactions among system components.

The complexity of a system is the degree of difficulty in predicting the properties of the system, given the properties of the system's components. To understand the complexity of a system, we need to build an intuition of how components of the system interact and how these interactions affect the overall system behaviors, responses, and outcomes (Czerwinski et al. 2000).

A complex system should possess the following typical characteristics (Bar-Yam 2002; Cilliers 1998):

1) *A large number of components*: Complex systems are composed of a large number of components. When the number is relatively small, the behavior of the elements can often be given a formal description in conventional terms. However, when the number becomes sufficiently large, conventional means (e.g. a system of differential equations) not only become impractical, they also cease to assist in any understanding of the system.
2) *Required connections:* All the components are connected in various ways. A connection is required if the system will never work or cannot work well when we remove the connection. For example, the human body has many interconnected components. If a component of the human body is disconnected, the body will often become injured and will not work well. In order

to constitute a complex system, the elements have to interact and this interaction must be dynamic. A complex system changes with time. The interactions do not have to be physical; they can be nonphysical, like the transference of information. Due to the presence of the required connections, there is a paradox *to divide a complex system into independent components*, i.e. if a system is complex, we cannot divide the system; if we can divide a system into independent components, then the system is not complex. This paradox confirms that complex systems are indeed complex.

3) *Collaboration:* After connecting with each other, components collaborate to provide the required functions of a complex system. Such collaboration can occur in different phases, such as communication, interaction, team formation, coordination, and cooperation. The aim of communication is sharing. Communication is the prerequisite of interaction. The objective of interactions is to influence each other. In a complex system, the communications and interactions are *spontaneous* and have a short range, e.g. email exchange, phone calls, or chat groups. Communications and interactions also have *recurrences* due to requirements. Team formation is required when components need to work together to function. To work as a team, participants must conduct coordination and cooperation.
4) *The locality of components*: Each component is not aware of the whole system behavior and it can only respond to the locally available information. If each element knew what was happening to the system as a whole, all of the complexity would have to be present in that element. This would either entail a physical impossibility, in the sense that a single element does not have the necessary capacity, or constitute a metaphysical move to the viewpoint that the consciousness of the whole is contained in one particular unit.
5) *Dynamics*: Dynamics means openness, development, and changing. Complex systems are usually open systems, which interact with other systems. In other words, it is not easy to define the boundary of a complex system. Complex systems are related to time. They have different states at different times. They evolve over time. The past states may affect the present and future behavior of the system. Changing is the only thing that is determined in complex systems. All the above characteristics will change with the development of the system along its timeline.

Please note that it is hard to divide a complex system into components. Such a situation seems in conflict with the first property in the above list. However, it is actually the two extremes of a complex system. A Chinese idiom saying "物极必反" read as "Wùjíbìfǎn," which means "things will develop in the opposite direction when they become extreme," clearly unveils this fact. Specifically, a complex system may have too many components for us to grasp and master them by classifying them into a limited number of components. Therefore, dealing with such a system as a whole might be an effective way.

1.7.2 Examples of Complex Systems

Now we discuss some examples of complex systems, which are on the cutting edge of research fields and could be modeled and handled by the proposed methodologies and models in this book.

1) The human body (Rettner 2016) is a typical complex system composed of subsystems, i.e. the circulatory, the digestive, the endocrine, the immune, the lymphatic, the nervous, the muscular, the reproductive, the skeletal, the respiratory, the urinary, and the integumentary systems; and organs, i.e. brain, heart, kidneys, liver, and lungs. These systems and organs are formed by the connections and collaboration of cells. The connections between these systems and organs are required. The major methodology of Western medicine is to "divide and conquer" and that of Eastern medicine is to consider the human body as a whole.
2) The Internet of Things (IoT) is defined as a phenomenon/system that every component in the context/system is connected with each other by a high-speed network. Such connections bring new and unforeseen benefits, advantages, and challenges. Everything such as cellphones, coffee makers, washing machines, headphones, lamps, and wearable devices can be connected with each other through an on-and-off switch to the Internet. In IoT, connections are obviously required, either wired or wireless.
3) A Cyber-Physical System (CPS) is defined as an integration of computation, networking, and physical processes. Embedded computers and networks can monitor and control physical processes, with feedback loops where the physical processes affect computations and vice versa (Lee 2008). The challenges of CPSs include: an appropriate level of abstraction, concurrency, interfacing, synchronization, and real-time control, where abstraction in a CPS needs to provide the right models for components and make the CPS easily analyzable, designable, implementable, and maintainable. Concurrency emphasizes that many components are running along their own threads; interfacing means that properly designed interfaces significantly affect the quality of a CPS; synchronization means that components in the CPS need to be synchronized in time to accomplish a designated task; and real-time control offers instant, stable, and anticipated behaviors of corresponding components.
4) A System of Systems (SoS) (Boardman and Sauser 2006; Maier 1998) is a collection of systems that share their resources and capabilities among each other to form a new, more complex system that offers more functionality and performance than simply the sum of the constituent systems. At present, an SoS is a promising research discipline that lacks models, frameworks, formal processes, quantitative analyses, effective tools, and well-accepted design methods.

An SoS presents the characteristics of autonomy, belongings, connectivity, diversity, and emergence in different forms other than those in a system of subsystems. It is different from a system of subsystems in that the components of an SoS are systems themselves but the components of the latter are just subsystems, which cannot exist independently and may lose one or more of the properties of a system. Therefore, a team of people is an SoS but a person is not because the components of a person cannot be an independent system itself, e.g. the head of a person cannot be an independent system. Robot teams are SoSs because a component or robot is an independent system. A software development team is an SoS because it is composed of components that can be independent systems, such as people, projects, products, and processes (Pressman 2014).

5) A social system is composed of numerous people. People interact with various relationships. The behaviors of social systems are dynamic and adaptive. Conventional ways of dealing with social systems are mainly from humanities, i.e. informal ways, because many problems in social systems are hard to formalize. A social system possesses all the properties of a complex system. The complexity of social systems comes mainly from the aspects of collaboration, i.e. sharing, connections, communications, interactions, coordination, and cooperation. Computational social systems (Wang 2014) are promising to develop better ways to deal with the problems of social systems.

We can continue this list, but it may deviate from our main topic on collaboration. The major idea we are pointing out is that complex systems definitely include collaboration. We believe that the models, methodology, and algorithms discussed in this book can be applied to all the areas discussed above, but we will need to use more effort and time to investigate and develop this.

1.8 Collaboration and Problem Solving

As we stated at the beginning of this chapter, collaboration is a complex problem. However, it is not only a problem but also a way of problem solving (Zhu 2009). Following the idea of object orientation, we may define the related concepts in problem solving. To differentiate objects after the concept of class is introduced, we need to define an *ordinary object*.

Definition 1.17 Everything in the world is an *ordinary object*.

We use $\overline{o}$ to express an ordinary object and $\overline{O}$ to express the set of all the ordinary objects in the world. In this chapter, objects are ordinary objects in the observable scope.

Definition 1.18 A problem $\overline{p}$ is defined as a tuple, $\overline{p}$:: = < $\overline{v}$, $\overline{a}$>, where $\overline{v}$ is an operation object, and $\overline{a}$ is an object called argument, $\overline{a}$ may be null. It can be also expressed as $\overline{v}(\overline{a})$.

We use $\overline{P}$ to express the set of all the problems. In a natural language, $\overline{v}$ is a verb and $\overline{a}$ is a noun. For example, "do(homework)" is a problem.

Definition 1.19 A *problem* $\overline{p}$ is complex if it has not yet been formalized or if the solution to it has exponential complexity.

Definition 1.20 A solution $\overline{s}$ is a way to solve a problem $\overline{p}$ or a concrete result of the way to solve $\overline{p}$. The symbol $\overline{s}$ denotes a specific solution and $\overline{S}$ denotes the set of all the solutions.

Definition 1.21 *Problem solving* for a problem $\overline{p} \in \overline{P}$ can be defined as an action to find a map <$\overline{p}$, $\overline{s}$ >, where $\overline{s} \in \overline{S}$.

In Definition 1.18, a problem $\overline{p}$ may be very simple or complex. For a specific problem $\overline{p}$, its map <$\overline{p}$,$\overline{s}$> may or may not exist.

Definition 1.22 *Collaborative problem solving* (Hsieh and O'Neil 2002) for a problem $\overline{p} \in \overline{P}$ can be defined as the activity of a group of people or intelligent entity to find a map <$\overline{p}$, $\overline{s}$ >, where $\overline{s} \in \overline{S}$.

Collaborative problem solving is one area for this book to contribute to.

Definition 1.23 *A problem solver* for a problem $\overline{p} \in \overline{P}$ can be defined as an active entity that conducts the action specified by $\overline{p}.\overline{v}$.

A problem solver can be a machine, a computer, a robot, a person, a team of people, or an organization.

Definition 1.24 A problem $\overline{p}$ is *solvable* if there is one solution $\overline{s}$ making <$\overline{p}$,$\overline{s}$> exist.

The **properties** of problems and problem solving are as follows:

1) One problem may or may not have a solution.
2) One problem may have many (>1) solutions.
3) A solution may be concrete or abstract.
4) The set of solutions $\overline{S}$ is expanding.
5) There are many forms of solutions.
6) A problem may be a compound problem, i.e. problem $\overline{p_1}$ is composed of *n* subproblems ($\overline{p_{11}}$, $\overline{p_{12}}$, ..., $\overline{p_{1n}}$). Note that we avoid using "complex," because a compound problem may not be a complex problem and an undividable problem may be a complex problem.

A problem may have no solution for the time being but may have a solution at a later time. For example, the problem “landOnByACar (theMoon)” has no current solution. “The homework done” and “learn, understand and do” are solutions to the problem “do(homework)”; “the homework done” is a concrete solution but “learn, understand and answer” is an abstract one; the problem “callOnAPlane (aFriend)” had no solution in the 1960s but has one now; mathematical problems have solutions in different forms, such as numbers, formulas, equations, tables, and graphs; health care problems also have solutions in different forms, such as pills, surgeries, and transplants; and software problems have solutions in the form of software systems.

From the above definitions, it is evident that “*collaboration*” is both a solution and a problem. It is a solution to a problem $\overline{p_s}$ that cannot be accomplished by a single person. It is also a problem $\overline{p_c}$ for the team of people who try to solve the previous problem $\overline{p_s}$. What we will discuss in this book is one specific solution, Role-Based Collaboration (RBC).

How to collaborate, or simply collaboration, is a complex problem, because it has not yet been formalized completely. Even though we divide collaboration into subproblems, these subproblems are still complex due to nonexistent formalization, or the high complexity of the formalized problem.

By reading this book, one may find that collaboration is an effective way to solve complex problems.

1.9 Summary

To understand the concept of collaboration as discussed in this book, we may need to take different standing points.

Collaboration can be a task for an administrator who will manage a group of people to work, i.e. collaborate. From the viewpoint of an administrator, collaboration concentrates on collectivism while considering individualism. The aim of this book is to provide a set of theories, models, methodologies, algorithms, and computer-based tools to support a group of components conducting teamwork.

Collaboration can also be viewed from an individual participating in collaboration, i.e. we may play a role as a participant. The models and formalizations in this book do not oppose this viewpoint, but rather encourage more research and investigations from this viewpoint. As a matter of fact, we investigated “how one could obtain a preferred position in a group from one agent’s viewpoint,” i.e. individualism (Zhu et al. 2018).

The fundamental goal of this book is to make collaboration easy. After we introduce the model and the methodology, we will be able to clarify the terminologies around collaboration from a more systematic and technical point of view. “Collaboration made easy” is the claim of this book.

Concepts are the first step of scientific research. They provide a basis in the formation of new models. Problem solving involves many fundamental concepts and mechanisms such as induction, deduction, abstraction, classification, and decomposition. Abstraction is the first thinking methodology for people to use when attempting to compose a new concept. It is necessary to define fundamental and abstract concepts and understand the basic properties of problem solving.

A problem can also be defined as a tuple of an operation and a real-world object. Such a definition may provide a guide on how to solve a problem, i.e. taking action to do the operation. Hence, collaboration is an anticipated action for solving a complicated problem.

In the following chapters, we mainly use agents as the participants of collaboration. We may also use people to emphasize natural collaboration or members to emphasize the relationships of parts (members) and the whole (the group).

It should be noted that readers may find that the following chapters try to resolve the issues discussed in this chapter. However, due to the complexity of collaboration, the author admits that there are still many related problems that have not been solved satisfactorily. The author welcomes interested readers to join the collaboration system research community to investigate more deeply and broadly to promote collaboration research.

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Exercises

1 Try to differentiate the following terminologies: collaboration, cooperation, coordination, communication, connection, interaction, interface, integration, sharing, and team.

2 Why do we conduct research in collaboration?

3 Try to differentiate collaborative systems from collaboration systems.

4 Explain why "collaboration" is a polymorphic word. Hint: You may consider the term "collaboration" as a problem, a system, a complex system, a problem-solving method, or a "divide and conquer" method.

5 Try to describe the differences and connections between the following terminologies: abstraction, model, information hiding, encapsulation, modeling, and classification.

6 What are the key components of collaboration?

7 What is the nature of collaboration?

8 Do you prefer collectivism or individualism in collaboration? Why?

9 Why is collaboration complex?

10 Give examples of complex systems and their connections to collaboration.

11 Explain why collaboration is both a problem and a solution to a problem.