P2P Frames: Pattern-based Characterization of Functional Requirements for Peer-to-peer Systems

Lirijan Sabani[a], Roman Wirtz[b] and Maritta Heisel

Working Group Software Engineering, University of Duisburg - Essen, Oststr. 99, 47057 Duisburg, Germany

Keywords: Requirements Engineering, Peer-to-peer Systems, Frames, Pattern, Functional Requirements.

Abstract: Peer-to-peer systems have become an essential element of computer networks and represent a special category of distributed systems. The strong decentralization as well as the scalability and fault tolerance are only some of the reasons why many companies have adopted this technology. Peer-to-peer systems consist of different subsystems, connected by a network. The decomposition into these subsystems requires a detailed analysis and documentation of functional requirements, which is a challenging task. In previous work, we proposed a method based on Jackson's problem frames approach that allows for modeling and documenting of functional requirements for distributed systems. To render knowledge about requirements for distributed systems reusable, we developed patterns as an extension for problem frames. However, these patterns (so-called frames) do not capture the specific characteristics of peer-to-peer systems. We thus analyzed typical requirements of peer-to-peer systems and observed several frames specific to peer-to-peer functionalities. We call these frames P2P frames. In this paper, we present frames for bootstrapping, query routing in unstructured networks, and the data transfer process in such systems. We also present our pattern system for requirements engineering, consisting of problem frames and frames for distributed systems, which helps software engineers to select suitable frames.

1 INTRODUCTION

In recent years, peer-to-peer (P2P) applications have become popular with millions of users and have been realized in various versions. In contrast to traditional distributed systems, a P2P system involves interaction between many subsystems (i.e., the peers). Peers can simultaneously assume the role of a client and server and run on different platforms, thus creating a decentralized network. P2P systems can be divided into two fundamentally different types: structured and unstructured. Structured P2P systems organize their peers in a structured graph and use indexes. These indexes enable the allocation of resources and peers. In most cases, this allocation is achieved by using a distributed hash table. Unstructured P2P systems have no global structure and establish connections between peers arbitrarily. The peers do not have access to any information about the resources available to their neighbors. Typical use cases for P2P applications range from filesharing services such as Gnutella to cryptocurrencies (e.g., Bitcoin). The functionalities of the different peers highly depend on each other, even though the subsystems are deployed on different hardware and operating systems. Therefore, it is not sufficient to consider a subsystem in isolation; rather, it is necessary to analyze a P2P system as a whole. Identifying the complex functionalities each peer must provide is a challenge for software engineers.

We aim to support software engineers from the beginning of a software development process (i.e., during requirements engineering). By following a pattern-based approach, we provide a systematic way to analyze and document functional requirements for P2P systems. In previous work, we proposed a method to document functional requirements for distributed systems (Wirtz et al., 2020) based on Jackson's problem frames. A problem frame is a pattern for a common problem during software development (i.e., a functional requirement). We extended Jackson's notation with elements for modeling the characteristics of distributed systems. Furthermore, we proposed an initial set of frames for distributed systems that capture typical distributed functionalities. However, the new frames are not specifically designed to

[a] https://orcid.org/0000-0003-0381-4643
[b] https://orcid.org/0000-0003-3260-4362

Sabani, L., Wirtz, R. and Heisel, M.
P2P Frames: Pattern-based Characterization of Functional Requirements for Peer-to-peer Systems.
DOI: 10.5220/0010434702390250
In *Proceedings of the 16th International Conference on Evaluation of Novel Approaches to Software Engineering (ENASE 2021)*, pages 239-250
ISBN: 978-989-758-508-1

meet the precise characteristics of P2P systems. Instead, they consider distributed systems in general.

In this paper, we refined the frames for this type of software systems. We began by identifying core functionalities of P2P systems (see Table 1). The bootstrapping mechanism is an essential task in P2P systems (Knoll et al., 2008; Boldt et al., 2017). The aim is to find an entry point into the P2P system to integrate a new peer. When a new peer wants to join a P2P system, the IP address and port of a peer that is currently connected to the desired P2P system must be discovered. Query routing among peers is also a key functionality for the correct operation of a P2P system, without which resource sharing would not be possible (Buford et al., 2008; Dinger, 2009). In this paper, we consider query routing in a decentralized and unstructured P2P model. In addition to bootstrapping and query routing, data transfer at the content level is also an essential requirement of P2P systems. The transfer of files is based on the information where the files are located.

For these functionalities, we identified a set of frames, each which describes a typical functional requirement in that context. We call these frames *P2P Frames*, which we describe in a consistent manner with a template. Each description consists of frame diagrams for the sender and the receiver, textual patterns for the functional requirement, and a set of known uses. Our second contribution is a frame library system that helps engineers to systematically identify suitable frames for their specific problem. Using a tree structure, our frame library system systematically describes the hierarchy between different frames, which allows one to structure the frame library. By adding newly identified frames to the frame library system, engineers can improve the library and adapt it to their own needs.

The remainder of the paper is structured as follows. In Section 2, we introduce Jackson's problem frames approach and our extension for distributed systems as background knowledge. Section 3 introduces our new set of so-called P2P frames for the mentioned requirements. In Section 4 we present an overview of our frame library system and describe how it can be integrated into a requirements engineering process. Using a small case study, we illustrate the application of our P2P frames in Section 5. We discuss related work in Section 6 and conclude the paper in Section 7 with a brief summary and an outlook on future research directions.

Table 1: Functionalities of P2P systems.

Name	Problem
Bootstrapping	How can peers join the overlay network?
Query routing	How can peers query information in an unstructured overlay network?
Data transfer	How can peers transfer data?

2 BACKGROUND

In this section, we introduce the basic concepts, notations, and terms that are necessary for further understanding. First, we introduce the concept of Jackson's problem frames (Jackson, 2000). Second, we describe our previous work on requirements engineering for distributed systems.

2.1 Problem Frames

For modeling functional requirements, we use the problem frames approach introduced by Jackson (Jackson, 2000). A problem frame is a pattern that classifies a typical software development problem (i.e., a functional requirement).

Jackson distinguishes between context diagrams and problem diagrams. The environment in which the machine (that is, the software to be developed) is operated can be represented by a context diagram (Jackson, 2000). The context diagram indicates where the problem is located and which domains it concerns. This diagram also displays who has control over the common phenomena. A context diagram, therefore, forms the basis for problem decomposition by projection. A problem diagram describes a concrete requirement and is an instance of a problem frame. The basic notation for such diagrams consists of domains, phenomena, and interfaces.

Jackson also distinguishes between two types of domains: machine domains and problem domains. Machine domains (represented by the symbol) represent the software to be developed. Problem domains represent entities of the real world that are relevant for that problem. There are different types of these domains: a biddable domain (represented by the symbol) represents an entity with an unpredictable behavior (e.g., humans). A causal domain (represented by the symbol) represents mechanical or electrical devices whose actions and reactions are predictable. A lexical domain (represented by the symbol) is used for data representation. To model a connection between two other domains (e.g., via technical devices), a connection domain (represented by the symbol) can be used.

Domains are connected via interfaces that are represented by solid lines. These interfaces consist of phenomena. Symbolic phenomena represent a type

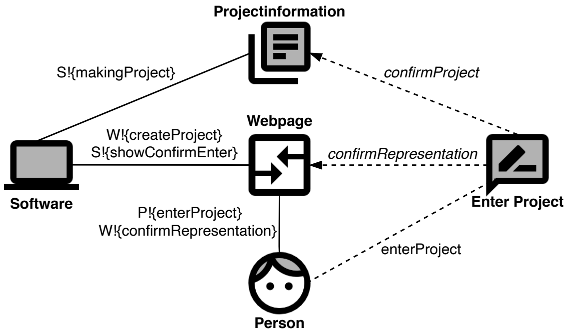


Figure 1: Example of a problem diagram.

of information or a state, while causal phenomena describe commands, actions and events. Each phenomenon is controlled by exactly one domain and can be observed by other domains. A phenomenon that is controlled by one domain and observed by another is called a shared phenomenon. An interface contains a set D!{...} of shared phenomena, where *D* is an abbreviation for the controlling domain.

In addition to domains and interfaces, a problem diagram contains a requirement (represented by the symbol) that is an optative statement. This statement describes how the environment will behave when the machine has been integrated. A requirement refers to an arbitrary number of phenomena. This is represented by a dashed line between the requirement and the controlling domain of the phenomenon to which the requirement refers. To describe the desired behavior of the environment, the requirement constrains at least one phenomenon. This constraint is represented by a dashed line with a filled arrowhead pointing from the requirement to the controlling domain.

Figure 1 is an example of a diagram for a functional requirement for creating a project. A *Person* provides information to the *Software* by entering all the necessary data to create a project. The *Webpage* represents the connection domain and serves as a link between the *Person* and the *Software*. The data is then stored in the database *Project-Information* and feedback is received via the *Webpage*. The functional requirement *Enter Project* refers to the phenomenon *enterProject* and constrains the phenomenon *confirmRepresentation* and *confirm-Project*.

2.2 Frames for Distributed Systems

In previous work, we extended Jackson's problem frames for an application in the context of distributed systems (Wirtz et al., 2020). In contrast to a problem frame, our approach considers not only a single system but also different subsystems. Therefore, each distributed frame consists of one diagram for the sender side and another for the receiver side.

2.2.1 Extended Notation

To analyze distributed systems, we introduce two new domain types. The domain type *Distributed System* (represented by the symbol) consists of at least two machine domains and covers all subsystems to be developed. To model the relation between the different subsystems, we introduce the domain type *Remote Machine* (represented by the symbol). By adding this domain to the diagram, we represent an interaction with another subsystem. The interface from a machine to a remote machine is a special one that we call *Remote Interface* (represented by a dotted line). Since the interaction between subsystems occurs via a network, the connection is considered unreliable.

To specify the interfaces between the domains more precisely in problem diagrams, the interfaces contain an attribute derived from the attack vector of the *Common Vulnerability Scoring System* (FIRST.org, 2019). The attribute can have one of the following four values: (i) *Network (N)* describes remote connections over different networks (e.g., via the Internet), (ii) *Adjacent (A)* represents local network connections, (iii) *local (L)* denotes access to domains that are not connected to the Internet, and (iv) *physical (P)* describes the physical connection to domains. A connection between a machine and a remote machine is either network or adjacent. A requirement can also be distributed. *Distributed requirements* are introduced to describe functional requirements that affect different subsystems.

2.2.2 Description Format

To specify frames for distributed systems in a consistent way, we provide a template (see Table 2 for an overview). The template consists of some basic information and a frame description.

Basic Information. We provide a short informal description that summarizes the frame and briefly describes the context for which it is applicable. The textual description of the functional requirement to be satisfied by the distributed system is also part of the informal description. The requirement will later be decomposed for the involved subsystems. In addition, we list typical examples of scenarios as known uses for the application of the frame.

Frame Description. We distinguish between the sender side and the receiver side. Since our approach is applicable for any type of distributed system, we do not use the notion of client/server side here. We provide a frame diagram for each side. A frame diagram contains the domain types, connecting interfaces, and requirement references for the frame. By instantiating the frame diagram in the concrete context, one can create a problem diagram. In addition to the frame diagram, we propose a textual pattern that describes the functional requirement in natural language. The notation "⟨...⟩" indicates a variable in the textual pattern that needs to be instantiated.

In the following sections, we use the template to specify our P2P frames.

2.2.3 Frame Overview

For distributed systems, we have identified seven frames. These frames are derived from problem frames (Jackson, 2000; Choppy and Heisel, 2004), and the abbreviation *DF* indicates a frame related to distributed systems.

Required Behavior (DF): One subsystem can control domains of its physical environment, and another subsystem can issue commands to control these domains. The task is to create a distributed system in which one subsystem's machine can remotely control domains in the physical environment of another subsystem.

Commanded Behavior (DF): A subsystem can control domains of its physical environment, and users can issue commands through another subsystem to control these domains. The task is to create a distributed system in which a user can remotely control domains in the physical environment of another subsystem.

Information Display (DF): One subsystem continuously receives information from the physical environment, and another subsystem has a display in its environment. The task is to exchange and display the received information between the subsystems.

Simple Workpieces (DF): A user can use a subsystem to edit some data, which can then be remotely accessed on another subsystem. The task is to transfer the commands to the subsystem where the data is available and to manipulate the data accordingly.

Transformation (DF): A subsystem's data are transformed. For the transformation of the data, another subsystem has to be used. The task is to develop a system to transfer data from one system to another to transform it. Then the transformed data is stored in the subsystem from which it originates.

Query (DF): A user can retrieve some information from a remote resource. The task is to develop a system to query that data from another subsystem and provide them to the user.

Update (DF): A user can modify some information that is available at a remote resource. The task is to develop a system to transfer the commands to modify the data to the subsystem and to provide an appropriate feedback to the user.

However, these frames for distributed systems do not capture specific characteristics of P2P systems. In Section 3, we describe frames particular to the identified core functionalities of P2P systems.

Table 2: Frames for distributed systems – Description format.

Basic Information	
Name	Short and descriptive name for the frame.
Description	Short informal description about the frame and the context for which it is applicable.
Known uses	List of typical examples where the pattern can be applied.
Frame Description	
Sender	
Frame diagram	Diagram that contains the relevant domains and interfaces on the sender side.
Textual pattern	Textual pattern for the relevant part of the functional requirement on the sender side.
Receiver	
Frame diagram	Diagram that contains the relevant domains and interfaces on the receiver side.
Textual pattern	Textual pattern for the relevant part of the functional requirement on the receiver side.

3 P2P FRAMES

In this section, we refine the frames for distributed systems (see Section 2.2) and propose *P2P Frames* to characterize specific problems that occur in the context of P2P systems. Each P2P frame is a special kind of frame for distributed systems and captures a specific functionality for a P2P system. Table 3 contains the name of each P2P frame and the domain types that are constrained and referred to on the sender and receiver side.

To consistently specify our P2P frames, we use the template that we described in Section 2.2.2. In the following sections, we present four P2P frames. First, we describe two frames for bootstrapping mechanisms. Then we outline a query routing frame, followed by a frame for transferring data.

3.1 Bootstrapping Frames

There are two classes of approaches for bootstrapping, namely peer-based approaches and mediator-based approaches (Knoll et al., 2008).

In the peer-based approach, peers can be discovered in the network by contacting known peers directly. Peer caches are a well-known example of this approach. A peer cache is a database of previously known peers. It is part of the P2P application's download file and is updated when a peer connects to the network. When a peer wants to join an existing network, it tries to contact one of the peers in its peer cache. If the contacted peer is available, it can be used as an entry point into the network (Knoll et al., 2008).

In the mediator-based approach, a well-known entry point, the mediator, is used to find other peers in the network. For example, mediators can be superpeers of the network or hosts provided by the operator of the P2P system. When a peer wants to join an existing network, it first contacts the mediator, which then returns connection information from peers that are currently active. A well-known example of this approach is a rendezvous server. A rendezvous server is a central server to which a joining peer can connect. This server returns a list of already participating peers.

We present our identified frames, *Bootstrapping Peer-based Approach (DF)* and *Bootstrapping Mediator-based Approach (DF)* in the following. Since P2P systems are a subset of distributed systems, we mark them with *DF* in the same manner as frames for distributed systems (see Section 2.2).

Bootstrapping Peer-based Approach (DF).

Description. A peer wants to join the overlay network. To join the network, a peer can use its peer cache to contact another peer in the network directly, without first contacting a mediator. The task is to develop a peer-based (peer cache) bootstrapping mechanism that allows a peer to join the network.
Known Uses:

- Most Gnutella clients have their own internal peer cache that stores IP addresses that were active when the client was last used.
- eMule also uses the peer-based bootstrapping strategy. Each peer has a cache list of servers.

Table 3: P2P Frames – Overview.

Name	Sender: Domain types referred to	Sender: Domain types constrained	Receiver: Domain types referred to	Receiver: Domain types constrained
P2P Frames				
Bootstrapping Peer-based Approach (DF)	*B*, *L*, *RM*	*RM*	*RM*	*RM*, *L*
Bootstrapping Mediator-based Approach (DF)	*B*, *RM*	*RM*	*RM*, *L*	*RM*, *L*
Query Routing (DF)	*B*, *RM*	*RM*, *C*	*RM*, *L*	*RM*
Transfer (DF)	*B*, *RM*	*RM*, *L*	*RM*, *L*	*RM*

Legend: ***C*** *– causal,* ***L*** *– lexical,* ***B*** *– biddable,* ***RM*** *– remote machine*

Frame Description. Table 4 depicts the frame description for the frame *Bootstrapping Peer-based Approach (DF)*.

On the sender side, the *User* initiates the connection between *Peer A* and *Peer B* with the event *E1*. Using information *Y1* from the *Peer Cache*, *Peer A* connects to *Peer B* with the command *C2*. *Peer B* confirms a successful connection with the command *C3*.

On the receiver side, *Peer B* receives the connection request from *Peer A* and confirms the connection (commands *C2* and *C3*). *Peer B* updates the *Remote Cache*'s information *Y2* with the command *C4*.

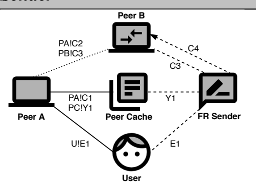
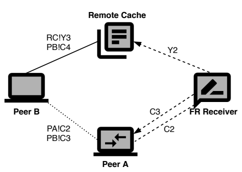
Bootstrapping Mediator-based Approach (DF).

Description. A peer wants to join the overlay network. To join the network, a mediator must be requested to provide a list of the peers in the network. The requesting peer then contacts one of the peers from the list. The task is to develop a mediator-based bootstrapping mechanism that allows a peer to join the network.
Known Uses:

- Gnutella also implements a distributed rendezvous server model called GWebCache, which is a web-based caching system that allows a client to request a list of online peers. In contrast to a peer-based approach, a rendezvous server works as a mediator to provide the list of known peers.
- Napster uses a directory service to find other peers in the network. The addresses of the central servers are hard-coded in the Napster client.

Frame Description. Table 5 depicts the frame description for the frame *Bootstrapping Mediator-based*

Table 4: Frame description for *Bootstrapping Peer-based Approach (DF)*.

Sender	***Receiver***
	
A ⟨User⟩ can request to join a network by connecting to ⟨Peer B⟩ using the peer descriptors from ⟨Peer Cache⟩.	⟨Peer A⟩ can establish a connection, and the ⟨Remote Cache⟩ can be updated with the corresponding information.

Approach (DF).

On the sender side, a *User* can initiate the event *E1* at *Peer A*. *Peer A* then connects to the *Mediator* with the command *C1* and receives the list of peer descriptors via command *C2*. Using this descriptor information, *Peer A* connects to *Peer B* with command *C4*. *Peer B* confirms the connection with command *C5*.

For the receiver side, we present two diagrams. The first describes the requirement for the mediator. *Peer A* connects to the *Mediator* with *C1*. The *Mediator* retrieves a *List of Peer Descriptors* (information *Y1*) with the command *C3* and returns it to *Peer A*. The second diagram describes the requirement for joining the network by connecting to a peer. *Peer A* can connect to *Peer B*, and *Peer B* confirms the connection (commands *C4* and *C5*). Furthermore, *Peer B* updates the information *Y2* of known peers at the *Remote Cache* with the command *C6*.

3.2 Query Routing Frame

In unstructured P2P systems, query routing is a challenging task. Unlike in structured P2P systems, there is no global directory containing data location information, and peers are connected arbitrarily. We focus on unstructured P2P systems in the following.

Each peer usually keeps a list of known peers (Buford et al., 2008), which are called neighbors. Messages can be exchanged with other peers in the neighbor list as soon as a peer is connected to the overlay network. An important message type is *Query*, which queries specific resources. The query includes search criteria such as the file name or certain keywords. It is not known which peers in the overlay network have the queried information. Therefore, a query can be sent to any known peer. If these neighbors do not have the information, they can forward the query to their neighbors, and so on.

Unstructured P2P systems typically use a local index-based search (Dinger, 2009). Each peer stores the directory of its own data objects locally. When a peer generates a query, it passes the query to peers in the network to locate the desired object. Our identified frame *Query Routing (DF)* is discussed below.

Query Routing (DF).

Description. A user wants to use a resource in the network and sends a query to one or more neighboring peers. When a neighbor receives a query message, it checks whether the requested file matches one of the files in its directory of shareable files. If there is a match, the neighbor returns a query hit message to the requesting peer. The requested information is displayed to the user. Each query hit message follows the reverse path of the query message. If there is no match, a peer forwards the query to its own neighbors recursively until the requested information is found. The task is to develop a routing mechanism.

Known Uses:

- Resource localization processes in P2P systems.
- An information request via a network.

Frame Description. Table 6 depicts the frame description for the frame *Query Routing (DF)*.

On the sender side, a *Query Initiator* can initiate the event *E1* on *Peer A* for requesting a resource. *Peer A* can forward the request to *Peer B* (command *C1*), and *Peer B* returns the resource via the command *C2*. Using the *Display*, *Peer A* can initiate the event *E2* to display the resource.

On the receiver side, *Peer B* can receive the request from *Peer A* (command *C1*). If it is available, *Peer B* can retrieve the requested resource *Y1* from the

Table 5: Frame description for *Bootstrapping Mediator-based Approach (DF).*

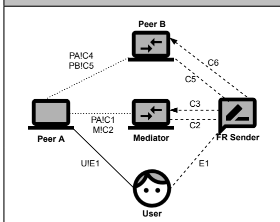
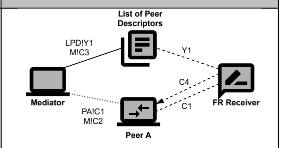
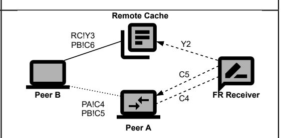
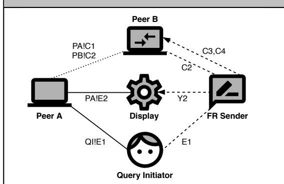
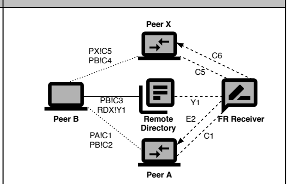
Sender	Receiver
	 ⟨Peer A⟩ can request a ⟨List of Peer Descriptors⟩.
A ⟨User⟩ can request a list of peers from the ⟨Mediator⟩ to connect to ⟨Peer B⟩.	 ⟨Peer A⟩ can establish a connection, and the ⟨Remote Cache⟩ can be updated with the corresponding information.

Table 6: Frame description for *Query Routing (DF).*

Sender	Receiver
	
A ⟨Query Initiator⟩ can request a resource from ⟨Peer B⟩ to be shown at the ⟨Display⟩.	⟨Peer A⟩ can request a resource. It can either be taken from the ⟨Remote Directory⟩, or the request is forwarded to another ⟨Peer X⟩.

Remote Directory using the command *C3*. If the resource is not available, *Peer B* forwards the request to another peer, *Peer X* (command *C4*). *Peer X* works in the same way as *Peer B* and will return the resource with the command *C5*. Finally, *Peer B* returns the resource to the initial *Peer A* (command *C2*).

3.3 Transfer Frame

P2P technologies are usually a simple approach for direct data transfer if one has the contact information of the peer with the queried data. A direct connection is established between them. Therefore, the protocols that access a resource are usually independent of the routing protocol. Well-known protocols like the HTTP protocol are used (Hauswirth and Dustdar, 2005). With this method, almost all kinds of digital media can be shared. Our identified frame *Transfer (DF)* is discussed below.

Transfer (DF).

Description. A user requests data from another subsystem. The requested data is stored on the user's storage device.
Known Uses:

- The use of resources in P2P systems.
- Downloading a file from a network.

Frame Description. Table 7 depicts the frame description for the frame *Transfer (DF)*.

On the sender side, the *Transfer Initiator* can initiate the event *E1* to transfer a file from *Peer B* to a *Local File*. *Peer A* forwards the request to *Peer B* with the command *C1*. *Peer B* then returns the file with the command *C2*, and *Peer A* stores the file at *Local File* with the command *C4*.

On the receiver side, *Peer B* receives the request from *Peer A* with the command *C1*. With the command *C3*, *Peer B* retrieves the *Remote File* (phenomenon Y1). Finally, *Peer B* returns the file to *Peer A* with the command *C2*.

In the next section, we present a frame library in which we integrate our P2P frames.

4 FRAME LIBRARY SYSTEM

To support the selection of suitable frames, we present our frame library system. Figure 2 depicts the hierarchal order in which it is organized. Our system can be integrated into a requirements engineering process to document functional requirements of software.

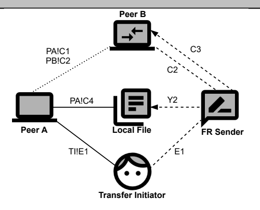
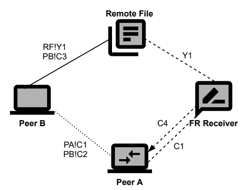
The root element is the *Frame Library*, which is a collection of suitable frames that are sorted by the type of system for which the frames are applicable. The starting point for selecting a suitable frame is the set of functional requirements, which are represented in natural language. Our frame library system assists engineers in selecting a suitable frame for each of these requirements. For each requirement, it is necessary to denote the appropriate type. We distinguish between non-distributed requirements and distributed requirements. A requirement that concerns at least two subsystems is considered distributed, and a requirement that concerns only one subsystem is non-distributed.

Depending on the type of requirement that is specified, our frame library system offers a subset of available frames. The category of distributed frames contains the basic frames specified for distributed systems (see Section 2.2), and the category problem frames contains a set of frames (e.g., (Jackson, 2000; Choppy and Heisel, 2004)) for non-distributed systems. If the distributed frames are not precise enough for a problem, requirements engineers can also select frames for special categories of distributed systems, for example, our P2P frames for P2P systems. These frames capture specific characteristics of system categories and are specifically adapted to them.

To ultimately determine whether a frame is applicable, engineers can compare the functional requirement with the frame description we provide with our template. If no suitable frame or combination of frames exists, the problem must be decomposed into smaller parts, or a new frame has potentially been identified. The new identified frame can then be documented in the frame library using the frame description template from Section 2.2.2. The template constitutes the foundation for the frame library. Using our description format, requirements engineers can easily specify their own distributed frames, thus leading to a consistently growing set of frames.

The frame library system can also be extended to

Table 7: Frame description for *Transfer (DF)*.

Sender	***Receiver***
	
A ⟨Transfer Initiator⟩ can transfer a resource from ⟨Peer B⟩ to a ⟨Local File⟩.	⟨Peer A⟩ can request a ⟨Remote File⟩.

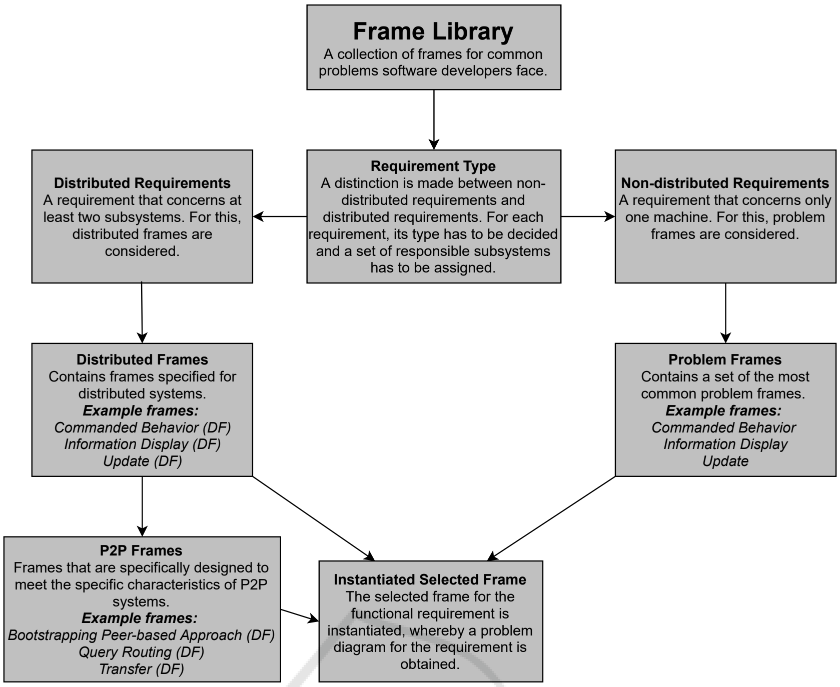


Figure 2: Frame library.

other types of distributed systems. If it is a special requirement for a specific distributed system, the distributed frames can also be used as a refinement basis, which can create an additional category of distributed frames, such as our new P2P frames. In this case, it is necessary to introduce a new category below the distributed frames. Identified requirements can then be sorted into a suitable category. If a suitable frame is found, it can be instantiated for the functional requirement by creating a corresponding problem diagram.

5 EXAMPLE

We illustrate the application of our P2P frames using a typical small filesharing system example. We first present an informal scenario description, a functional requirement for the system, and the context diagram with the identified subsystems. We then document the requirement in a problem diagram by instantiating an appropriate P2P frame.

5.1 Informal Description and Functional Requirement

The filesharing shall be realized as an unstructured P2P network with no central file directory. To join this unstructured P2P network, peers must execute a bootstrapping function. Here we use a mediator-based bootstrapping approach. After joining the network, peers can exchange files with each other. For the example, we focus on the bootstrapping requirement, which can be formulated as follows:

> ***Join the network*** Peers can join the network using a mediator to retrieve peer holder descriptors (i.e., IP addresses of already participating peers).

Problem diagrams for the other requirements, *Searching for a file* and *Transferring a file*, are included in the appendix.

5.2 Context Diagram and Subsystems

In Figure 3, we present the context diagram and the subsystems for our example.

The context diagram contains the *File Sharing Service*, which we derived from the informal scenario description. For the distributed system, we further identified three subsystems. The *User Peer* is employed by users of the P2P network for bootstrapping and requesting files from other peers. The *Overlay Service Provider* is the mediator server that provides the peer descriptors for the bootstrapping process. Finally, the *File Holder Peer* represents a peer from which a user can request files. Furthermore, this peer can be used for bootstrapping since its IP address is available at the overlay service provider.

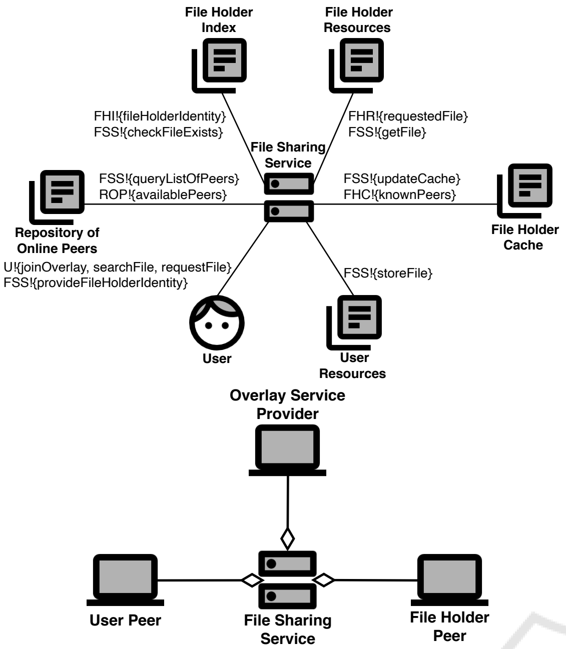


Figure 3: Example – Context diagram and subsystems.

In the context diagram, we document domains that interact with the distributed system: A *User* can initiate a command to join the overlay and can search for and request files. The distributed system provides a *Repository of Online Peers* that contains the peer descriptors. When a new peer connects to an existing peer, this existing peer's *File Holder Cache* is updated with the new peer's information. The *File Holder Index* is the index of available files at a file holder peer, and the *File Holder Resources* are the files. A user's files are represented by the *User Resources*.

5.3 Select Frames

We use our frame library (see Section 4) to determine a suitable frame for documenting the functional requirement. For the requirement *Join the network*, we select the frame as follows. Since it is a distributed requirement, we consider distributed frames as relevant. Because the requirement is related to P2P systems, we further consider our P2P frames. The requirement fits to the frame *Bootstrapping Mediator-based Approach (DF)* (see Table 5).

In the next step, we create the problem diagrams for each subsystem by instantiating the frame.

5.4 Create Problem Diagrams

Since the requirement *Join the network* is distributed, we create a problem diagram for each of the involved subsystems: (i) *User Peer*, (ii) *File Holder Peer*, and (iii) *Overlay Service Provider*. The interface to problem domains in the environment (e.g., lexical domains) can be taken from the context diagram, whereas the interfaces between the different subsystems (i.e., peers and overlay service provider) are not yet contained in the context diagram. The context diagram considers the distributed system as a whole. Therefore, it is necessary to describe the interaction between the subsystems in the problem diagrams by defining appropriate interfaces and phenomena.

User Peer. Figure 4 presents the problem diagram for the requirement *Join the network* with regard to the subsystem *User Peer*. Since the *User Peer* initiates the connection with the other subsystems, we instantiate the sender frame diagram for it. Using the textual pattern, the corresponding functional requirement can be formulated as follows:

> A *User* can request a list of peers from the *Overlay Service Provider* to connect to *File Holder Peer*.

The diagram contains the machine itself, the *User* who initiates the bootstrapping process, the *Overlay Service Provider*, and the *File Holder Peer*. Between the user and the machine, there is a physical interface containing the command *joinOverlay*, which is initiated by the user. The interfaces between *User Peer*, *Overlay Service Provider*, and *File Holder Peer* are remote interfaces that describe the interaction between the different subsystems of the file sharing service (see Figure 3). Since these interfaces are not yet contained in the context diagram, they are defined in the problem diagrams. The *User Peer* can request a peer to connect from the *Overlay Service Provider*. Afterwards, the *User Peer* joins the overlay using the *File Holder Peer*, which grants access to the network.

The requirement refers to the phenomenon *joinOverlay* of the *User*, the phenomenon *grantRequestHP* of the remote machine *File Holder Peer*, and the phenomenon *returnPeerToConnectOSP* of the remote machine *Overlay Service Provider*. It constrains the phenomenon *queryListOfPeers*, which is the command to retrieve the online peers, and the phenomenon *updateCache* of the *File Holder Peer*.

Overlay Service Provider. The problem diagram for the *Overlay Service Provider* is included in Figure 5. The *Overlay Service Provider* is the mediator and receives requests from the *User Peer*. We therefore instantiate the first receiver frame diagram for this subsystem. It consists of the machine, the *Repository of Online Peers*, and the *User Peer*.

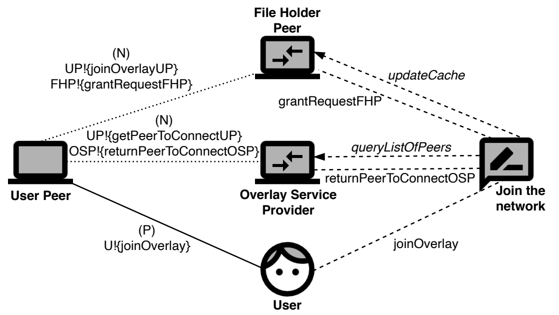


Figure 4: Example – Problem diagram for *User Peer*.

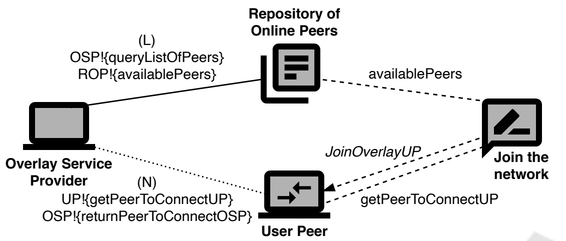


Figure 5: Example – Problem diagram for *Overlay Service Provider*.

With the textual pattern, the functional requirement for the subsystem can be formulated as follows:

> *User Peer* can request a *Repository of Online Peers*.

Since *Peer User* and *Overlay Service Provider* communicate via the Internet, the interface is a network interface (N). There is a local interface (L) between the *Overlay Service Provider* and the *Repository of Online Peers*.

The *Overlay Service Provider* receives the request for a peer to connect from the *User Peer*. The machine queries the list of available peers from the repository and returns a peer to connect to the *User Peer*.

The requirement refers to the phenomenon *availablePeers* (*Repository of Online Peers*) and to the phenomenon *getPeerToConnectUP* (*User Peer*). In addition, the requirement constrains the phenomenon *joinOverlayUP* to trigger the establishment of the connection to the returned peer.

File Holder Peer. Figure 6 presents the problem diagram for the *File Holder Peer*. We instantiate the second receiver frame diagram for this subsystem since it receives the request to connect from the *User Peer*. It contains the machine, the *File Holder Cache*, and the *User Peer*.

The functional requirement for the subsystem can be formulated as follows using the textual pattern:

> *User Peer* can establish a connection, and the *File Holder Cache* can be updated with the corresponding information.

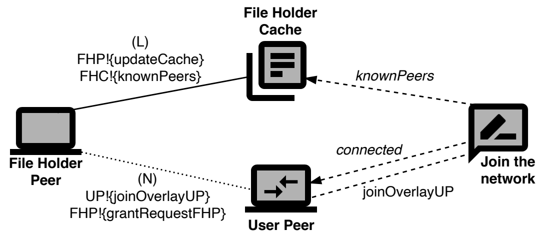


Figure 6: Example – Problem diagram for *File Holder Peer*.

The *File Holder Peer* receives the request from the *User Peer* to join the overlay. Afterwards, it upgrades the cache with information about the new peer and grants access to the network.

The requirement refers to the phenomenon *joinOverlayUP* (*User Peer*), and it constrains the phenomenon *knownPeers* (*File Holder Cache*), which represents the list of known peers in the cache, as well as the phenomenon *connected* (*User Peer*), which represents the *User Peer's* now connected state.

In this example, we have successfully divided our described problem (connecting to an existing P2P system) into smaller subproblems. The created requirements model now serves as a scaffold for the design phase to derive an architecture for the system.

6 RELATED WORK

In the following section, we discuss related work that follows a similar approach or that may complement our work.

Our frames only address functional requirements. For non-functional requirements such as security, special P2P frames must be defined. There are problem frames that constitute patterns for representing security problems (Hatebur and Heisel, 2005). These are specific types of problem frames defined to capture known approaches to ensure security. It would be interesting to extend our frames to the analysis of relevant security requirements for P2P systems to consider security concerns from the beginning of the development process.

Beckers et al. have proposed context patterns that enable a structured elicitation of domain knowledge for specific technologies such as P2P systems (Beckers et al., 2013). The instantiated context patterns can be used as a basis for writing precise requirements. These authors have also based their approach on Jackson's work. Since we focus on functional requirements, these proposed context patterns and our frames for distributed systems can complement each other in a requirements engineering process.

There are several design and architecture patterns in the context of P2P systems (Amoretti and Zanichelli, 2018; Grolimund and Müller, 2006). The resulting pattern catalogs support the design and implementation phases of the software engineering process, while our work focuses on the requirements engineering phase. By mapping our frames to appropriate design and architectural patterns, we can also assist the design phase during software development.

Haley suggests to use cardinalities to problem diagrams to specify interfaces between domains in a distributed system in more detail (Haley, 2003). Adding cardinality notation to P2P frame diagrams would allow us to specify the communication between different subsystems in more detail.

There are also improvements for P2P techniques in general, such as combining peer caches with a mediator (Knoll et al., 2008). Such proposals attempt to combine the advantages of both approaches. With the help of our two bootstrapping frames, which now serve as a basis for refinement in addition to the basic frames for distributed systems, hybrid bootstrapping variants that combine these approaches can be modeled more easily.

Finally, a literature review discusses the current status of requirements engineering for distributed computing (Ramachandran and Mahmood, 2017). The authors focus on cloud computing, which has become increasingly popular in recent years. While we have limited ourselves to P2P systems in this paper, their work can serve as input for further analysis of frames for distributed systems in the context of cloud computing. Our frame library could be extended to include special cloud frames.

7 CONCLUSION AND FUTURE WORK

Summary. The main contribution of our paper are P2P frames, which capture typical functional requirements in P2P systems. These patterns are an extension of Jackson's problem frames and the frames for distributed systems. We restricted ourselves to bootstrapping, query routing in unstructured networks, and direct data transfer between peers. Since we use a consistent description format, the set of frames can easily be extended. In addition, we proposed a frame library system that supports the process of requirements engineering and that also incorporates our new P2P frames. This library system helps software developers to systematically identify suitable frames for their functional requirements. They can instantiate a selected frame for their specific problems. Each frame for distributed systems can be further refined to capture specific aspects of distributed systems, thereby establishing new categories of frames (e.g., our P2P frames). Our library can be integrated into requirements engineering processes and supports the selection of suitable frames to document functional requirements.

Outlook. In future work, we plan to extend our frame library system with new categories (e.g., frames for cloud computing). Our created P2P frames currently represent a basic set of typical requirements in P2P systems. We will continue to extend our library to incorporate a growing set of frames. To make our system publicly available, we plan to implement it as a web service. Requirements engineers can look up suitable frames. Furthermore, they can contribute to the library by adding their own identified frames. It would also be interesting to extend the idea of P2P frames to the analysis of security-relevant requirements for P2P systems to address security concerns from the beginning of the development process.

In summary, we believe that patterns should be part of a software analyst's standard toolkit and that a comprehensive and extensible catalog helps both experienced developers as well as those with no P2P systems experience.

REFERENCES

Amoretti, M. and Zanichelli, F. (2018). P2P-PL: A pattern language to design efficient and robust peer-to-peer systems. *Peer Peer Netw. Appl.*, 11(3):518–547.

Beckers, K., Faßbender, S., and Heisel, M. (2013). A meta-model approach to the fundamentals for a pattern language for context elicitation. In *Proceedings of the 18th European Conference on Pattern Languages of Programs (Europlop)*.

Boldt, D., Felix, K., and Fischer, S. (2017). Decentralized Bootstrapping for WebRTC-based P2P Networks. *The Fifth International Conference on Building and Exploring Web Based Environments (WEB2017)*, pages 17–23.

Buford, J., Yu, H., and Lua, E. K. (2008). *P2P Networking and Applications*. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA.

Choppy, C. and Heisel, M. (2004). Une approache à base de patrons pour la spécification et le développement de systèmes d'information. *Approches Formelles dans l'Assistance au Développement de Logiciels - AFADL*.

Dinger, J. (2009). *Das Potential von Peer-to-Peer-Netzen und -Systemen : Architekturen, Robustheit und rechtliche Verortung*. Universitätsverlag Karlsruhe, Karlsruhe.

FIRST.org (2019). Common vulnerability scoring system v3.1: Specification document.

Grolimund, D. and Müller, P. (2006). A pattern language for overlay networks in peer-to-peer systems. In Zdun,

U. and Hvatum, L. B., editors, *EuroPLoP' 2006, Eleventh European Conference on Pattern Languages of Programs, Irsee, Germany, July 5-9, 2006*, pages 95–140. UVK - Universitaetsverlag Konstanz.

Haley, C. B. (2003). Using problem frames with distributed architectures: A case for cardinality on interfaces. In *ICSE 2003 - Proceedings of 2nd International Software Requirements to Architectures Workshop, STRAW 2003, May 9, 2003, Portland, Oregon, USA*, pages 130–133.

Hatebur, D. and Heisel, M. (2005). Problem frames and architectures for security problems. In Winther, R., Gran, B. A., and Dahll, G., editors, *Computer Safety, Reliability, and Security, 24th International Conference, SAFECOMP 2005, Fredrikstad, Norway, September 28-30, 2005, Proceedings*, volume 3688 of *Lecture Notes in Computer Science*, pages 390–404. Springer.

Hauswirth, M. and Dustdar, S. (2005). Peer-to-peer: Grundlagen und architektur. *Datenbank-Spektrum*, pages 5–13.

Jackson, M. A. (2000). *Problem Frames - Analysing and Structuring Software Development Problems*. Pearson Education.

Knoll, M., Wacker, A., Schiele, G., and Weis, T. (2008). Bootstrapping in peer-to-peer systems. In *14th International Conference on Parallel and Distributed Systems, ICPADS 2008, Melbourne, Victoria, Australia, December 8-10, 2008*, pages 271–278. IEEE Computer Society.

Ramachandran, M. and Mahmood, Z. (2017). *Requirements Engineering for Service and Cloud Computing*. Springer, 1st edition.

Wirtz, R., Heisel, M., and Wagner, M. (2020). Distributed frames: Pattern-based characterization of functional requirements for distributed systems. In *Software Technologies - 14th International Conference, ICSOFT 2019, Prague, Czech Republic, July 26–28, 2019, Revised Selected Papers*, volume 1. Springer International Publishing.

APPENDIX

Search File.

In Figures 7 and 8, we present the problem diagrams for the requirement that users can search for files in the network.

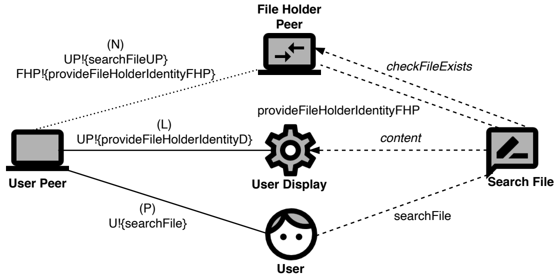


Figure 7: Example – Search file for *User Peer*.

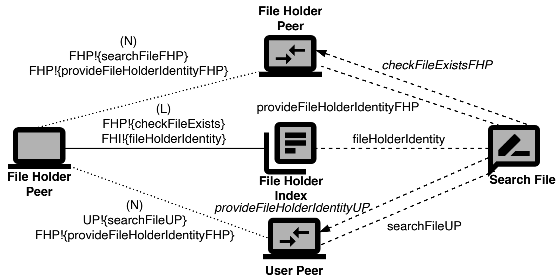


Figure 8: Example – Search file for *File Holder Peer*.

Transfer File.

In Figures 9 and 10, we present the problem diagrams for the requirement that users can transfer files from another peer to their own one.

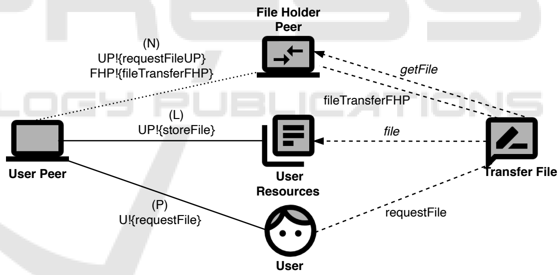


Figure 9: Example – Transfer file for *User Peer*.

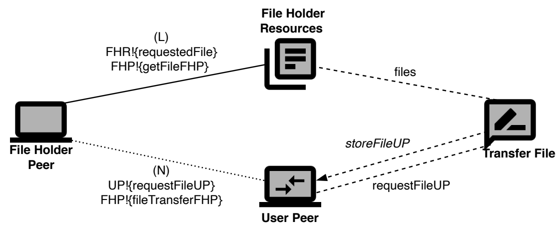


Figure 10: Example – Transfer file for *File Holder Peer*.