

Decomposition, Depositing and Committing of Digital Footprint of Complex Composite Objects

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Abstract. The article presents the issue of describing complex composite objects of intellectual activity (OIA), which are placed and maintained in information systems using distributed ledger technology (blockchain). The essence of fragmentation is described, a classification of the stages of maturity of deposited OIAs and their structural configurations is introduced. An approach to decomposition and internal markup of composite objects is described. Examples of depositing such objects on the IPUniversity platform (a composite OIA markup module) are given, as well as recommendations on organizing the work of registries operating with complex objects of intellectual activity.

Keywords: Objects of intellectual activity · Composite object · Distributed ledger technology · Digital footprint · Depositing · IPUniversity platform

1 Introduction and Related Works

The implementation of scientific, educational, and industrial activities today is linked with the creation of various digital objects. Managing the processes of creating and using such objects usually involves committing data about objects in special registries, as well as monitoring their digital footprint. As a rule, such objects have a complex structure and heterogeneous composition. Heterogeneity can manifest itself through the imposition of markup on the integral image of the object, reflecting different points of view during the analysis [1,3]. This is also true for results of intellectual activity obtained by one author or a whole team. The value of such objects is determined not only by the content of the object, but also by the history of its formation, as well as the events above it. Thus, when forming the value (utility) of such an object, it is necessary to take into account both the results of intellectual activity and the volume and features of the formation of its digital footprint. It is often very important to fix, consider and use such objects not only at the technological level, but also at

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the level of copyright management. In a number of cases, the distribution speed and the commercialization potential depend on the formation completeness of the objects of intellectual activity (OIA) digital footprint and guarantees of its fidelity [9,21]. Therefore, the commit and maintenance of complex composite objects requires a qualitative approach to organizing their structure within the framework of specialized information systems (for example, based on distributed ledger technology).

Digital objects play a special role among OIAs, because the information space in which they are formed is able to commit those changes that increase the potential value of the OIA instance for the end user. For this reason, it is interesting to look at a digital OIA in conjunction with its digital footprint as a composite entity in dynamics [20].

OIAs are subject to copyright or patent law and are effectively protected by law only when copyright priority can be proven. For these purposes, there are various patent organizations and special registries that involve carrying out the object through the deposit procedure. If this procedure is supplemented with the mechanisms of distributed registries (blockchain), it is possible to guarantee the tracking of all changes and operations on the object as well as the agreement of all parties to the terms of smart contracts as confirmed by special certificates [10].

Meanwhile, the description of objects in such registries is very standardized and it is not possible to produce a qualitative description of heterogeneity. Let us consider the characteristics of information systems operating in the Russian Federation, aimed at depositing digital OIAs, as an example: estimates are given by experts, where V is the capability realized, and ∼V - the capability is partially realized (see Table 1). The table shows that the digital footprint of an object of intellectual activity (OIA) and the structural heterogeneity of objects are not committed or are only partially committed. For this reason, it is important to consider the fragmentation issue not only from a conceptual and technological point of view, but also taking into account legal specifics.

An analysis of the technology of depositing and patenting in various countries and industries (for example, the works of [12,14,17,21]) showed a similar situation: composite OIAs are described and registered either as a single object, or each independently. At best, authorship is described by the CRediT [15] model, which does not involve decomposition of OIAs. If industry platforms with mechanisms based on distributed ledger technology are used to manage OIAs, then we agree with the conclusion made in the [21] study about the need for "extensive research" mechanisms for depositing and maintaining objects.

The purpose of our study is to describe an approach to formalizing the decomposition of data on complex composite objects for their commit and further maintenance in systems based on distributed ledger technology. For this, we define the essence of composite objects and introduce their maturity stages within the concept of distributed registries; present a typology of variants of structural fragmentation; briefly describe the approach to decomposition and formalization of data on composite objects; provide examples of the decomposition of composite

Table 1. Capabilities of information systems depositing OIAs in the Russian Federation.

Deposit systems for objects of intellectual activity	Number of specifications for OIA types	Digital footprint commit	Additional files	Application of blockchain technology	External fragmentation	Internal fragmentation	Description of fragments
– Federal Institute of Industrial Property (www.fips.ru)	4	–	V	∼V	–	–	–
– Unified Depository of Intellectual Activity Results (www.edrid.ru)	5	–	–	V	–	–	–
– National Intellectual Property Registry (www.nris.ru)	5	–	V	V	V	–	V
– Russian Science Citation Index (www.elibrary.ru)	1	∼V	–	–	–	–	–
– (C)opyright.ru (www.copyright.ru)	10	–	V	–	–	–	–
– Digital Platform of Knowledge Sharing and Copyright Management (www.ipuniversity.ru)	15	V	V	V	V	∼V	V

OIAs for the IPUniversity system (https://ipuniversity.ru) [5]; give recommendations on the organization of registries that support the deposit of composite OIAs.

2 Method

2.1 Composite Object and Maturity Stages of Its Commit

According to Aristotelian logic [7], the whole and the part form a dialectical unity and demonstrate a systemic effect, which is also called emergence. Therefore, a composite (or fragmented) OIA is an entity that can be decomposed into parts without losing the integrity of its perception. Based on the methodology of the system approach [2,13], the description of the object can be carried out from various points of view. For us, within the framework of this work, the structural, semantic, authorial and external (borrowing) aspects will be of interest.

Digital objects of intellectual activity are characterized not only by the possibility of their exact copying, but also by the possibility of observing the actions

that were performed on them during operations in a digital environment. These actions (operations) form a digital footprint that accompanies an OIA in the form of additional information (metadata) stored jointly or separately from the object (provided they are unambiguously correlated). These metadata appear gradually, expanding the useful amount of information about an OIA itself. Consequently, the genesis of a digital OIA should take place in a certain information environment aimed at increasing the intensity of the OIA turnover. From this position, a number of stages of the objects formation (maturity) can be distinguished:

- a zero stage (creation) - when an object has received a digital form and is not fixed within that information environment/platform (it is a file or a group of them on a data medium).
- the first stage (initialization) - when an object is entered into the system and is completed with a minimum set of identification data (as a rule, it is an identification number, affiliation with the author and date), it may have an incomplete appearance both in description and in structural elements.
- the second stage (description) - when an author commits a description (metadata) for an object that allows it to be effectively represented, searched and evaluated, and the description of its constituent elements is detailed and changes are made (editing).
- the third stage (deposit) - when a public identifier (registration number) is assigned to metadata, and the forms corresponding to the deposit procedure are committed (there may not be public access to an object), and an object itself is placed in a certain register of objects and becomes a full-fledged object of copyright.
- the fourth stage (patenting) - when a number of forms for patenting are committed and an object gets into the register of patents (there may not be public access to an object).
- the fifth stage (turnover) - when an object becomes the subject of property or non-property transactions (for example, through smart contracts), recorded in the information environment as independent events.
- the sixth stage (embedding) - when inclusion/citation events are recorded for the object, allowing to establish the facts of its use by consumers (this stage is characterized by the presence of metrics, for example, [18]).
- an additional stage (rating, "+") - when the metadata of an object is supplemented with external ratings (likes, comments, reviews, inclusion in reviews, etc.), which allows you to determine the range of potential consumers and determine consumer qualities (this stage is characterized by the assessment of altmetrics, for example, [16]).

The maturity stages stated above depend on the purpose for which the information environment is created, in which OIAs should be placed (from a simple file storage to a full-fledged industry-wide distributed registry). Some objects will stop at the first stage and immediately "acquire" operations, citations and/or external evaluations. Others will consistently reach the fourth stage and only

after that will form the elements of the footprint responsible for interacting with consumers.

The connection of the formation processes of internal (author's)/external (consumer's) elements of the digital footprint by stages is presented in Fig. 1, conditionally divided into three zones - legal, descriptive and operation. All these data become inseparable from a digital OIA and are stored in the registry. Such an approach allows us to conclude that the totality of aspects, entities and processes that define a digital OIA with a heterogeneous structure needs to identify typical structures.

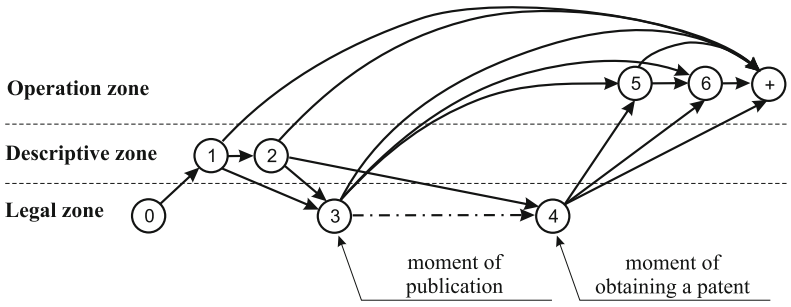


Fig. 1. Formation paths of the digital footprint elements of a composite object relative to the maturity stages.

2.2 Structures of Composite Objects

The methodology of the system engineering approach [13] suggests that the manifestation of fragmentation (decomposition) of an object must be considered from various points of view (aspects). As the basic aspects, we choose the structural, semantic, authorial and external (borrowing) aspect.

The first, and the most obvious, approach is the decomposition of the internal structure into blocks that are heterogeneous in nature. For example, for objects of a textual nature, these are blocks of text, images, tables, and formulas; for audiovisual objects, this is the separation of text/music, audio and video series. For databases - tables and data schemas. For information systems - program listings, flowcharts, and window interfaces. For log reports of automated training systems, this is the path of movements between didactic units, answers to control and measuring materials and questions of questionnaires, etc. The specificity of this type of fragmentation is that blocks can be specified explicitly, relying on the obvious isolation of each of them.

The second approach, i.e. semantic, takes semantic fragments as the basis for division, which an author decided to subjectively isolate into a separate block, for one reason or another. For example, for a text, it can be entire chapters or

sections that carry semantic and logical isolation; for a piece of music - parts; for an information system - functions, etc.

The decomposition by author's contribution (the third approach) is based on the degree of each co-author's participation in the formation of one or another structural element of an OIA. For some objects, you can specify the contribution ratio as a whole (transferred to any fragment), while for others, this ratio is so individualized that it records the contribution of each in an explicit form. But there is a case when there is a role division of the contribution [22]: for example, one was the author of the idea, the other supervised the work, and the third and fourth performed it. Then, the author's contribution is indicated subjectively, noting the role of each performer or their groups (for example, relying on the CRediT approach [1]).

The fourth approach (highlighting borrowings) reflects the relations of external OIAs with the deposited ones. An author has the opportunity to highlight those blocks that are borrowed from other sources (directly or indirectly). Then, the knowledge representation about the author's contribution A will be a tuple of (1) type:

$$A =< S \times F \mid L, H >, \tag{1}$$

where S is a selected set of structural fragments of an object (nodes), F is a set of groups of co-authors' activities (for example, in accordance with the CRediT approach), L is a set of structural links between nodes, H is a set of co-authors and copyright holders. This makes it possible to take into account direct citations, references and even creative processing (modification) [23].

Any of the approaches stated above can be taken as a basis for decomposition, and in some cases, they should be combined. Furthermore, internal fragmentation can be combined with external fragmentation. Let us consider the variants of internal and external relations between fragments and objects forming composite OIAs (see Table 2). One should draw attention to that committing an OIA within the registry requires a unique ID that allows you to associate events with an object and include them in the digital footprint.

The table shows that OIAs in the registry can be represented in the form of entities describing a specific object file in metadata, as well as an assembly of objects (Fig. 2), contains graphic images of each OIA decomposition variant (where M is a metadata block, P is a fragment description, F is an associated file, and the "*" sign indicates pointers (links) to external entities). The uppercase and lowercase designation of metadata refers whether a corresponding block has its own (M) or secondary (m) identification number. The presence of its own metadata in a fragment does not guarantee its isolation as an independent OIA. The latter kind of arrangement assumes hybrid relations and/or more than two levels in the object inclusion hierarchy.

2.3 Approach to the Description of External and Internal Fragmentation

Let us move from theoretical issues of the process of describing composite objects to practical ones by illustrating the implementation of these capabilities within

the framework of a digital platform for committing composite OIAs. Fragmentation (selection of component parts) presupposes the answer to two questions: "What characterizes a fragment?" and "Where are its boundaries?". The answer to the first question corresponds to the metadata that an author enters into the information system during the deposit process. They are stored in a special database and/or registry and are descriptive of the OIA files themselves. The answer to the second question is not quite obvious and leads to the need to separate the external and internal fragmentation of an OIA.

Table 2. Characteristics of composite OIAs.

Composite type	Deposited entity	Links to external files	Structural blocks (more than one)	ID holder	Examples
1) Single-level simple	One main simple file	No	No	Main OIA file	– block diagram of the algorithm; – DNA sequence file
2) Single-level composite	One main file with fragments	No	Yes	Main OIA file	– preprint of a scientific article
3) Single-level detailed	One main file with a complex structure and external supporting files	Yes	Yes	Main OIA file	– monograph preprint
4) Two-level simple	Virtual object with a description of files as a single collection	Yes	No	Aggregate entity	– atlas; – many images as data-set for AI algorithms (archived)
5) Two-level composite	Virtual object with a description of each file	Yes	Yes	Aggregate entity	– library of design objects as an independent OIA, consisting of a set of OIAs
6) Two-level detailed	Virtual object with a description of each fragment as an OIA	Yes	Yes	Aggregate entity and each fragment	– preprint of a collection of scientific articles published in the registry as independent OIAs
7) Multi-level	Virtual object as an aggregator of a set of nested OIAs	Yes	Yes	Aggregate entity and individual fragments	– e-learning course

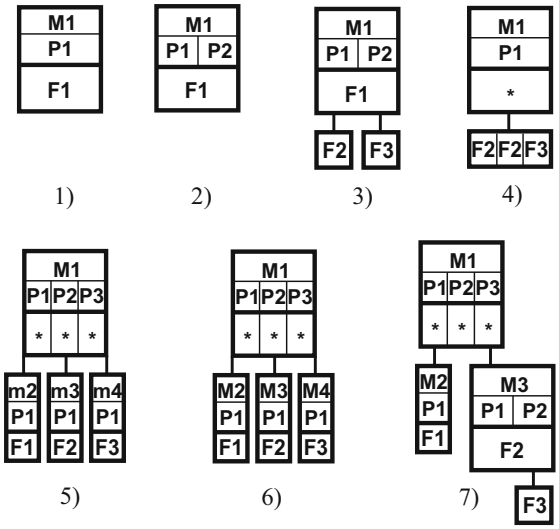


Fig. 2. Conditional graphic sample for OIAs decomposition.

Internal fragmentation, as a process of describing parts of an OIA in the form of separate blocks, implies the presence of a mandatory and variable part of metadata. The mandatory part will include such data about an OIA as the title, authors, date of deposit, identification number, link to the file with the object and several others. The variable part of the metadata depends on the nature of the object and its consumer qualities, which set the accents in the description. If the object has a predominantly textual nature (preprints of scientific articles, digital collections, patents texts, scientific reports, dissertations, etc.), then they can be described in accordance with any (even the most complex) graphical decomposition pattern (see variants in Fig. 2). This implies that each fragment contains a link not only to an OIA file or an supporting file, but also the inclusion of block boundaries in the structure of the file (more precisely, its copy). Markup can be used as a mechanism, i.e. embedding service information (tags) into the OIA structure, which allows to describe all aspects of decomposition at the same time: sequential selection of fragments of a composite OIA and their description [24]. It is convenient to implement the fragment boundary selection mechanism in the form of a WYSIWYG editor, and mark the blocks using the mouse pointer.

External fragmentation is primarily determined by the specifics of the associated OIA objects, which are independent files (up to entire archives). They are presented as images, block diagrams, log reports of scientific equipment, etc. Examples 4–6 and Example 7, with some restrictions, from Fig. 2 correspond to this case. Data about fragments will b independent identifier in the

object registry. The component parts will either be just attached files, i.e. have a description, but do not have their own unique identifiers (Examples 4 and 5); or will be external attachable OIAs previously entered in the registry and having their own identifiers (Example 6).

2.4 IPUniversity Platform

The IPUniversity (https://ipuniversity.ru) [5] platform became the information system on the basis of which the research on the decomposition, depositing and committing of the digital footprint was conducted. It was developed in order to simplify and accelerate the turnover of OIAs between scientific and educational organizations of the Russian Federation and interested consumers. The platform work is based on the organization of the business logic of the OIAs turnover with their deposit, storage and commit of transactions using distributed ledger technology. The deposit module allows you to commit a digital OIA by performing the following sequence of actions: Federation

- initialize a new OIA and enter a primary description;
- attach a file with a digital version of the object, or get it from previously placed in the registry;
- describe the OIA fragments using the markup module [24];
- formalize links with external objects;
- send an OIA for registration in the registry, having previously agreed with all co-authors, using the digital signature mechanism.

The result of the work of the platform internal mechanisms are the created copies of an OIA in the repository, as well as the corresponding entry in the registry (including all metadata reflected in an object card). An example of an object card [25] is shown in Fig. 3.

The platform supports 5 types of licenses for managing access to OIAs through the mechanism of smart contracts based on PoS consensus. Each OIA, after its successful placement in the registry (see Fig. 4a), is assigned a special registration number (IPC identifier). According to the object certificate, you can both verify the object itself and get access to the chain of its smart contracts and its digital footprint (see Fig. 4b).

3 Case Study

Let us consider the correlation of OIAs with structural types in two examples. To begin with, let us take the OIA, presented as a RAW file with the results of mass spectrometry (Fig. 5), obtained using the Waters Acquity I CLASS Xevo TQD equipment for the substance $C_{30}H_{26}BrN_3O_4$ [8]. Here, primary data sets combined in the form of an archive are considered as a single object that has common identification data in the registry (corresponds to decomposition Example 3). In this case, the author's layer includes scientists, researchers, as well as

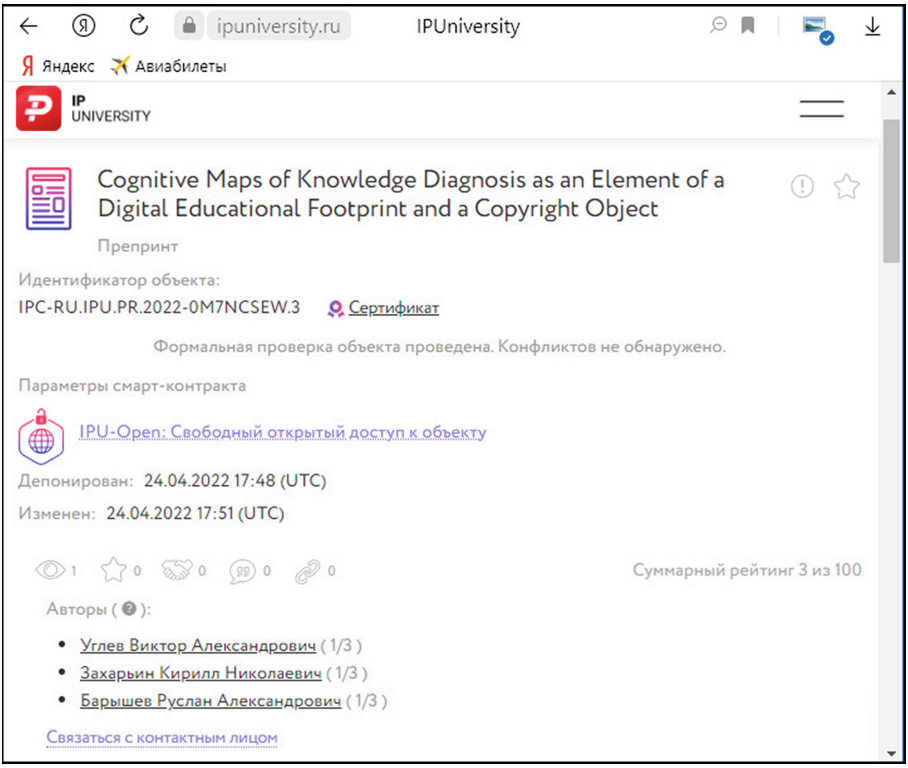


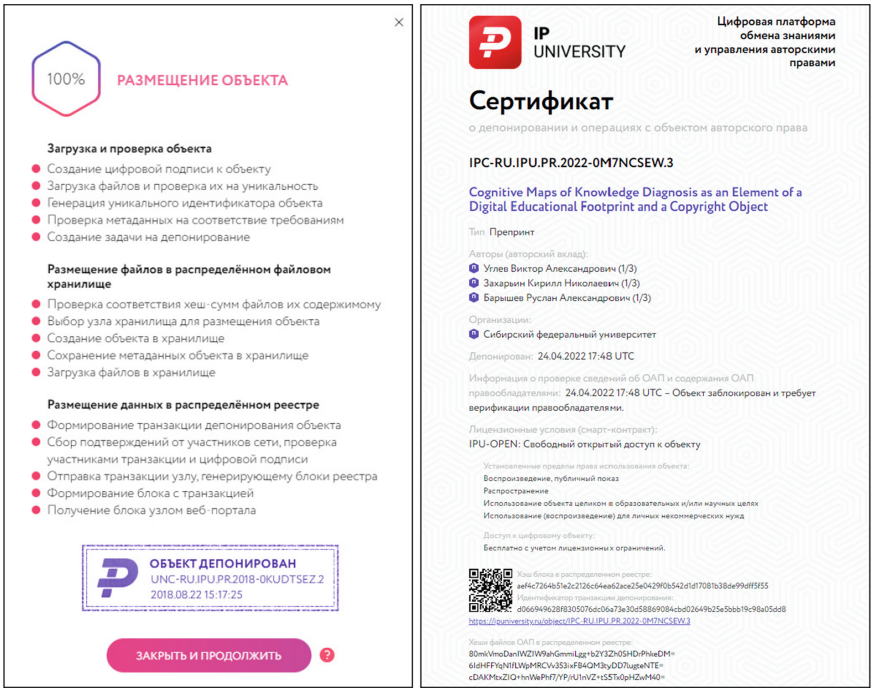
Fig. 3. Object card [25] in the IPUniversity registry.

a laboratory assistant and a head of the laboratory of the organization on the basis of which the spectrogram is obtained.

The second example is the OIA as a result of the work of an intelligent training system for a specific student (part of the educational digital footprint recorded by the LMS [19]). Structurally, this configuration of a composite object corresponds to the decomposition Example 7 and is shown in Fig. 6 in a simplified way. The basic e-course model in the LMS Model itself is a composite object with a rather complex internal structure (mbz format), therefore, within the digital footprint, it has the character of external borrowing. Internal links, for example, include an atlas of Cognitive Maps of Knowledge Diagnosis [22], which play the role of a knowledge base relative to the digital footprint. Thus, the OIA turnes out to have both internal heterogeneity and references to external objects.

Now, let us consider another example typical for describing the internal fragmentation of composite objects using the markup module [24] integrated with the IPUniversity platform. As an object, we choose a scientific article [22], which has structural, semantic and authorial heterogeneity, as well as borrowings.

Let us dwell in more detail on the process of describing the internal fragmentation of this OIA, using a special markup module [24], made in the form of



(a) (b)

Fig. 4. Depositing process stages for object [25] and its certificate.

a WYSIWYG editor (markup is carried out using a computer mouse pointer). Figure 7 shows a fragment of a window that allows you to formalize the position of structural and semantic blocks:

– metadata (green colour);
– meaningful fragments of the work (light brown colour);
– a list of sources from which the borrowing is carried out (gray colour).

Each fragment has its own metadata, including the ability to specify external links both to other OIAs from the registry (by IPC identifier) and to objects from the Internet (by DOI or link to an Internet page). In the example, this corresponds to Example 3 of Fig. 2. Then the author's contribution for each fragment is indicated.

In the following screen form (see Fig. 8) the markup of borrowings from internal sources is shown (here from the list of references). To do this, the depositing author selects fragments that relate to one of the following types of borrowing:

– direct citation (red colours of the selection from Fig. 8);
– citation with addition;
– mention (not direct citation, blue colours of the selection).

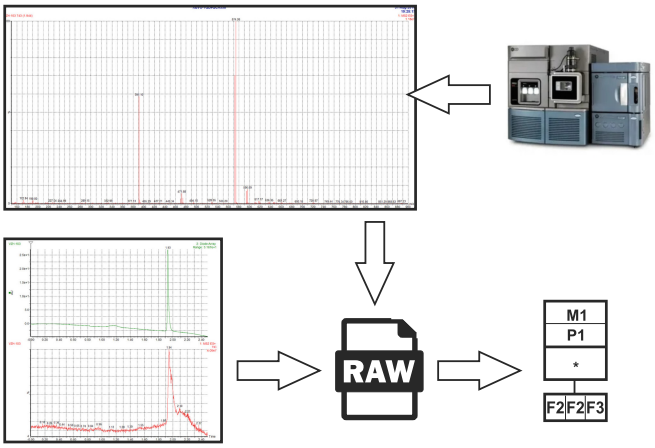


Fig. 5. Mass spectrogram as an inhomogeneous OIA.

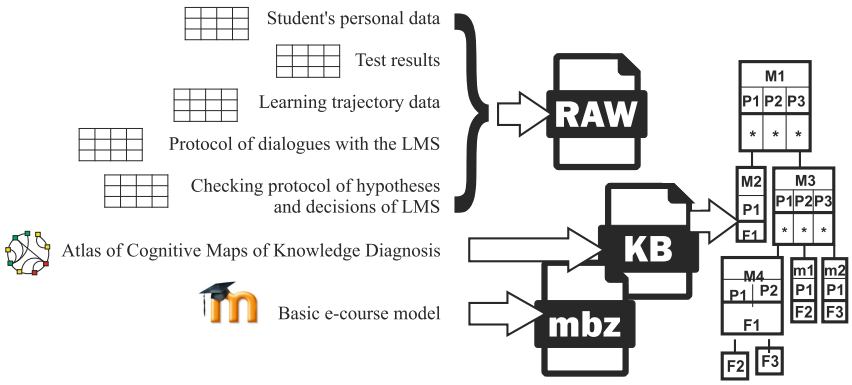


Fig. 6. Educational digital footprint as an OIA.

These types of borrowing allow, during subsequent analysis, to automatically evaluate the contribution of each co-author and evaluate a number of parameters of an OIA itself (for example, the indicator of "author's purity"), as well as introduce original metrics for a fractional assessment of the citation of an object/author (for more details, see [23]). By analogy, it is possible to formalize the internal heterogeneity of an OIA free text by highlighting and describing each fragment in the markup module.

4 Results and Discussion

The practice of depositing OIAs as composite objects was applied on the IPUniversity platform, focused on the scientific and educational content of educational organizations in Russia. Of the 15952 objects placed, 65% were text OIAs

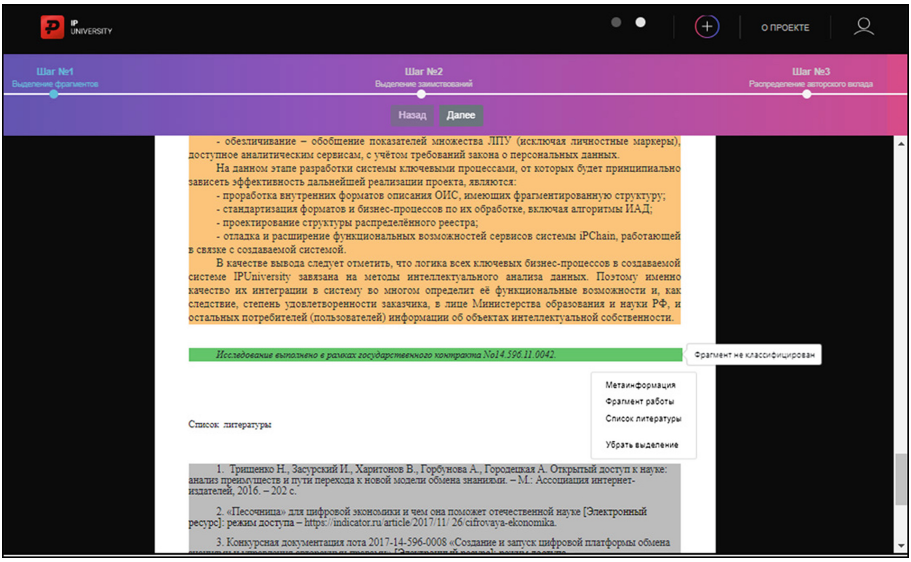


Fig. 7. Fragments of the internal markup windows of the OIA structural blocks on the IPUniversity platform (Color figure online)

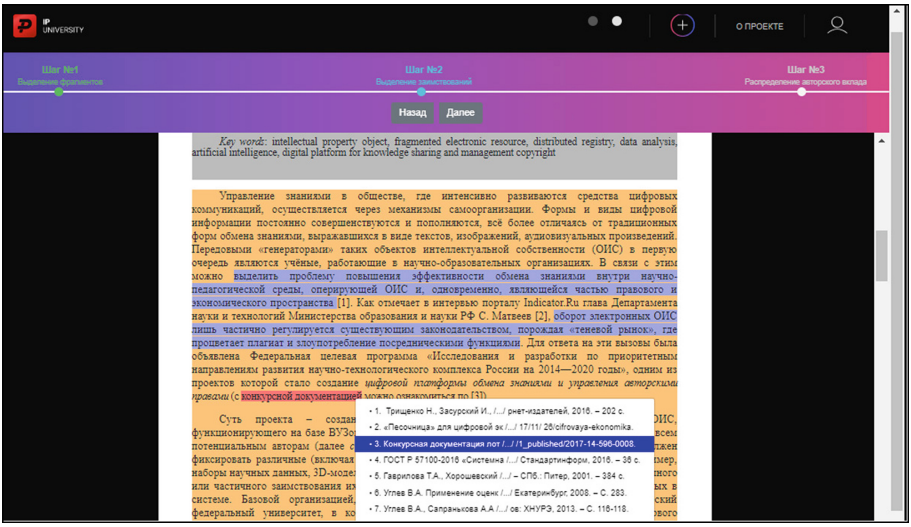


Fig. 8. Fragments of the internal markup windows of the OIA reference fragmentation on the IPUniversity platform (Color figure online)

(preprints), the authors of which had access to the internal fragmentation module. Feedback from the objects authors allowed us to summarize the experience gained and formulate a number of recommendations for developers of registries with composite objects:

- the purpose of the fragmented description of an OIA and its advantages should be practically useful and become in demand at higher stages of object maturity;
- metric estimates of fragmented OIAs should be understandable to a wide range of authors and have a clear practical significance, motivating to a conscious description of the objects structure;
- fragment description fields should be completed with tips and examples, and the process itself should be organized step by step;
- entering data on fragments should be carried out by the authors of an OIA personally, since the third-party performers involved do not have information about the semantic aspect of fragmentation and the specifics of the borrowings made;
- fixing the digital footprint for an OIA should have address links to the relevant fragments to which certain events relate (including smart contracts that meet the requirements of the fourth generation of blockchain technology [6]).

The practical implementation of the registry, which supports the possibility of describing composite objects, had a number of difficulties. In particular, many authors carried out the markup formally, without delving into the specifics of the approach. In addition, the analytical services of the platform at the time of the study were not yet equipped with advanced analytics tools to get the maximum benefit from the availability of data on the internal and external heterogeneities of deposited objects.

As prospects for the development of this approach, the following can be distinguished:

- the ability to create new metrics for evaluating individual OIAs, portfolios of digital assets, individual authors, author teams and departments by analyzing knowledge about external relations between fragments of various OIAs (rating tasks, selection, forecasting, etc.);
- - the ability for a decision-maker to visualize the OIA profile in much greater detail than similar services, such as citation maps in Scopus and Web of Science [4], allow;
- the ability to operate with large arrays of data on the OIA portfolio as Big-Data (tasks of finding patterns, identifying trends [11]);
- the ability to more flexibly maintain objects and their digital footprints in case of their migration between registries throughout their life cycle;
- the ability to use the markup module in combination with other services (primarily analytical) of the digital ecosystem of the organization where fragmented OIAs are the norm (for example, in scientific and educational institutions, as a service https://prometheus.sfu-kras.ru).

Thus, the introduction of composite objects into practical

5 Conclusion

Composite objects recorded as digital OIAs have a number of advantages in relation to OIAs that do not have fragments. Firstly, these are a more flexible description and, as a result, expanded prospects for turnover. Secondly, such objects can be claimed in parts, which makes it possible to more fairly take into account the interests of co-authors when distributing rewards. Thirdly, this is taking into account the genesis and turnover of fragments (especially in the presence of links and fixing borrowings), which allows more adequate assessment of metric and altmetric indicators, i.e. the significance of the result and the author's priority. In addition to this, it becomes possible to separate primary (protocols, RAW files, questionnaires, Data Sets, etc.) and secondary (reports, articles, monographs, and even entire projects) results of intellectual activity during decomposition.

Using the example of the IPUniversity platform, based on the mechanism of distributed registries, we see that it becomes possible not only to fix the right to a non-standard OIA object, but also to form it from heterogeneous data, without missing the contribution of each co-author to the corresponding fragment. This certainly expands the boundaries of the use of digital objects of intellectual property in legal, economic, scientific and applied aspects.

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