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Data Economy and FDOs

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Abstract. The FDO One project aims at building a global integrated dataspace based on FAIR digital objects (FDOs). The project's main contributions are the development of a publicly accessible FDO infrastructure, an international FDO testbed and bridges between multiple emerging dataspaces. These dataspaces are defined by important industrial standards, such as the Eclipse Dataspace Connector (EDC) implementing the specifications of the IDSA and the industry 4.0-technology Asset Administration Shell (AAS). A layered architecture as the basis for the common data infrastructure is designed and tested providing an important prerequisite for the efficient data sharing and re-use. Possible applications include the facilitation of AI training which can be democratized using open standards and publicly available data infrastructures.

Keywords: FAIR, FAIR Digital Objects, Data Management, Global Integrated Dataspace

1. Introduction

1.1 Global Integrated Dataspace

Societies and economies are in the process of a huge transformation. Increasingly often, digital data and smart algorithms operating on the data will greatly influence human decision makers or act autonomously with direct consequences for health and life, for the efficient usage of resources, for successful manufacturing processes, and much more. Since about the year 2000 researchers started to aggregate and integrate data and information that is stored in distributed repositories to be able to calculate free parameters by statistical analyses and infer new knowledge. In particular the growing understanding of algorithms first called "artificial neural networks" and their evolution to large performant software packages for deep learning led to a boost of articles about the increasing value of data not only for advanced science but also for economy. Without the need for a priori knowledge, multimodal data could be used to feed these machines such that models would emerge that could isolate patterns in very large data sets. The important task is then to collect suitable data and in case of supervised learning use appropriate annotations to guide the training.

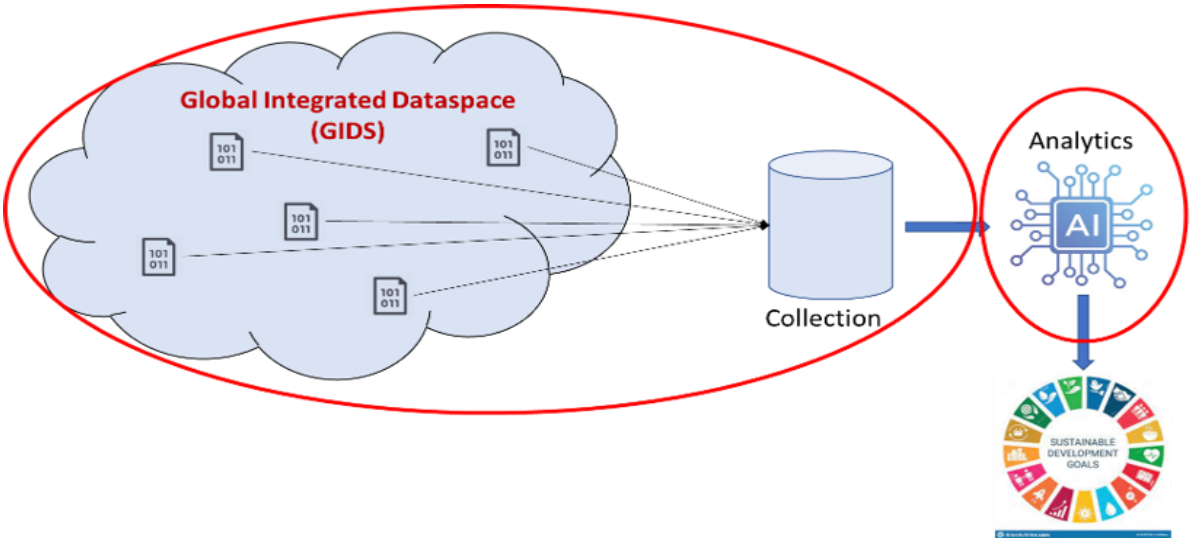

Figure 1. *indicates how the Global Integrated Dataspace will facilitate the aggregation of useful data for feeding AI machines to optimise human decision taking, based on simple and open mechanisms to help democratise AI while maintaining data sovereignty.*

In order to allow small companies and the public to develop, adapt and train AI tools, they need access to sufficient quantities of appropriate data. This could be facilitated by creating a globally integrated domain of data that is based on a unifying infrastructure. In the 1970ies the dream of an interconnected domain of computers was realised based on a simple and open technology (datagrams and TCP/IP) and in the 1990ies an integrated domain of information was developed based on a simple and open technology (html and http). According to G. Strawn, one of the Internet pioneers, it is now time to build the integrated domain of data that also needs to be built on top of a simple and open technology. Here we call this domain the Global Integrated DataSpace (GIDS) and we are certain that due to the economic potential of such a globally integrated domain, it will quickly become accepted. As indicated in Figure 1 it will allow users to find and aggregate data into collections which then can feed for example AI machines dedicated to address the Sustainability Development Goals [1]. Of course, compliance to legal and ethical regulations is crucial.

1.2 Increased Funding

Since about 2010 governments and also companies recognised the enormous importance of these new mechanisms and invested in large programs (see below) to support better data integration and to increase data interoperability. Large multinational companies which own broadly used social media applications or portals were amongst the first who had access to large amounts of data allowing to use these new mechanisms massively and realising their big economic value. In most areas of research and economy, however, useful data is being created, managed and stored in very different contexts using a wide range of different data organisations, formats and technologies. Furthermore, it is not straight-forward to access and explore these data. The result of this heterogeneity and fragmentation is well-known from studies in research and industry: about 80% of the time and money in data-driven projects is lost with data munging/wrangling [2]. Data-driven projects where data is going to be used from different “silos” are expensive and often still not possible. In addition, there are many social, legal and ethical aspects that pose a challenge to the easy sharing of data.

It seems intuitive, that increased sharing of high-quality data based on interoperability standards would reduce those costs. In recent years powerful cloud technologies were developed which are an important component of efficiently operating data infrastructures that enable sharing of data. However, most of the research and business data is stored in various repositories using all kinds of technologies (clouds, file systems, databases, etc.), i.e. the huge treasure of data is “hidden” behind a wall of heterogeneity (dark data) and needs to be unlocked by appropriate infrastructures.

The European Commission and also the various member states of the European Union started to launch large programs to improve data integration and interoperability across silos. Here we can only indicate a few:

(1) The ESFRI process started in 2009 and led to about 55 funded projects about 20 of which became legal entities from 2012 on [3]. One major task of most of these projects was to establish what is now called “dataspaces”. A dataspace includes a set of partners that share a specific scientific or economic goal and agree on a set of regulations and technologies to integrate distributed data to achieve this goal. Therefore, a dataspace is a type of a federation.

(2) EUDAT [4], OpenAIRE [5], EU flagship projects [6], and the setup of centres of excellence [7] were other programs and projects that were funded which included the establishment of dataspaces in some form.

(3) The publication of the FAIR principles in 2014 [8] inspired another wave of funding programs such as EOSC [9] and the German NFDI program [10]. The improved integration and interoperability was a central goal and resulted in dataspaces, i.e. definition of technologies, terms of sharing etc.

(4) In industry we saw important initiatives such as Industry 4.0 (I4.0), International Dataspace Association (IDSA) and Gaia-X. I4.0 resulted amongst others in the Asset Administration Shell (AAS) [11] which provides a standard to digitally describe lifecycle-related properties of mainly physical assets but which is also associated with a complete suite of software allowing to share data based on contractual regulations. Another core development was driven by the IDSA which addressed the issue of tightly controlled access to shared data and which resulted in the Eclipse Dataspace Connector (EDC) technology [12]. The Gaia-X programme, and in particular the Gaia-X-Federation services project, resulted in the Eclipse Cross Federation Services Components [13, 14] that support secure interaction between different services and some vertically organised projects that apply EDC and XFSC as for example Mobility Dataspace [15] and Catena-X [16].

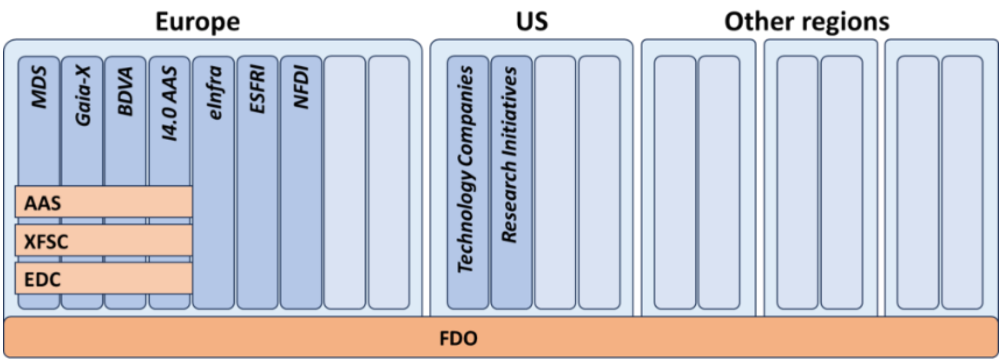

***Figure 2** illustrates how FDOs can serve as a basis layer (orange box at the bottom) for different regions with varying regulations (large white boxes) that host multiple dataspaces and initiatives (blue boxes). Additional technologies like EDC, AAS or XFSC can be used to add for example access restrictions or identity management.*

Similar programs with different foci were launched also in other regions such as US, Canada, Japan and China resulting in a large number of different dataspaces all being based on different sets of regulations and technologies as indicated in Figure 2. We see an urgency for steps towards convergence and unification to counteract the ongoing fragmentation and heterogeneity, although we may still be in the necessary phase of “creolisation” where new concepts are being tested out. It is agreed worldwide that the FAIR principles can be seen as a milestone in this development, since they summarize the grown knowledge about proper data creation and treatment in an excellent way. However, the FAIR Principles are not a blueprint for data infrastructure building. By basically demanding “machine actionability” they are a solid basis for automatic processing of data which will be the dominant way of data handling in the future. The term “machine actionability” means that mechanisms need to be in place which allow machines to take an action without human interaction when they identify an item (concept, category) in the structure they are processing.

1.3 Mission AI & FDO One

The German Government also realised the relationship between AI usage and efficient data infrastructures. The Mission AI program [17] wants to stress specific AI aspects on the one hand and also the bridge building between dataspaces on the other hand. The FDO One project [18] which is presented in this paper is meant to demonstrate that FAIR Digital Objects (FDO) [19] are indeed a technology that allows building bridges between dataspaces of different kinds and thus creating a unified, connected domain of data.

In this document we assume basic knowledge about FDOs and only briefly touch technologies such as EDC and I4.0 AAS. We describe first that the establishment of GIDS will require a layered structure of dataspaces, then discuss the basic pillars of the FDO One project, elaborate on aspects of automatic processing and draw some conclusions.

2. Layered Structure of GIDS

In fact, all ESFRI projects with distributed data, one of the core papers of EOSC [20], and the US OSTP report [21], stress the relevance of trustworthy and sustainable data repositories as stable pillars for the emerging domain of sharable and re-usable data. Such repositories will need to fulfil a number of requirements, which may differ between research and industry, and are embedded in a hierarchy of regulations. It is already common practice that larger repositories are part of different federations or dataspaces, i.e., they need to adhere to different regulations and interface with different technologies as indicated schematically in Figure 3. The black square would indicate that the repository is part of the GIDS which means that it must accept certain global technology standards to be interoperable and respect the role of the standardisation organisation. The coloured squares indicate that contractual relations are agreed on by different sets of partners which define under which regulations and with help of which technology data is being shared.

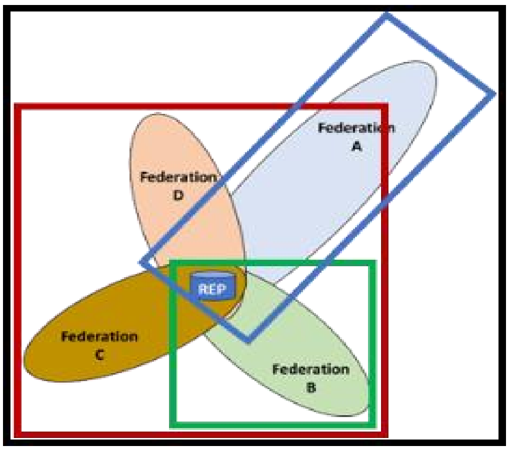

***Figure 3** schematically indicates that repositories as care takers of sharable and reusable data are and will be part of different dataspaces which all have legal and technical requirements.*

As one example we could take a repository which is part of the international network of climate modelling centres participating in the World Climate Reporting to the UN. To be part of this network repositories need to agree on the CMIP standard [22] and to share certain validated data with their partners. On the other hand, they need to adhere to institutional, national and partly regional regulations and technology specifications to offer specific data or metadata to national or regional information hubs. Another example would be an industrial repository from a car building company which will adopt a (hypothetical) agreed universal standard, would share specific data with its international subsidiaries, other data with its international providers of parts, other data with its international dealers and even other data to provide Digital Product Passports for its products. All these would be based on contracts that specify specific technology components to be applied and that adhere to the respective legislations.

As the Internet and Web experiences have shown, any suggestion to establish a globally accepted unification standard may not get involved in dealing with rights and legislations. TCP/IP and HTTP were successful because they are simple, open, non-proprietary and transparent to specific reuse conditions for the messages they exchange. However, there must be secure ways to transport such conditions so that higher layers can deal with them. The same holds for data objects: there must be a generic integration standard which does not deal with specific access conditions and is thus operating across institutional and national borders, but which allows actors to transport access condition specifications and verifications in a secure way to the next layer.

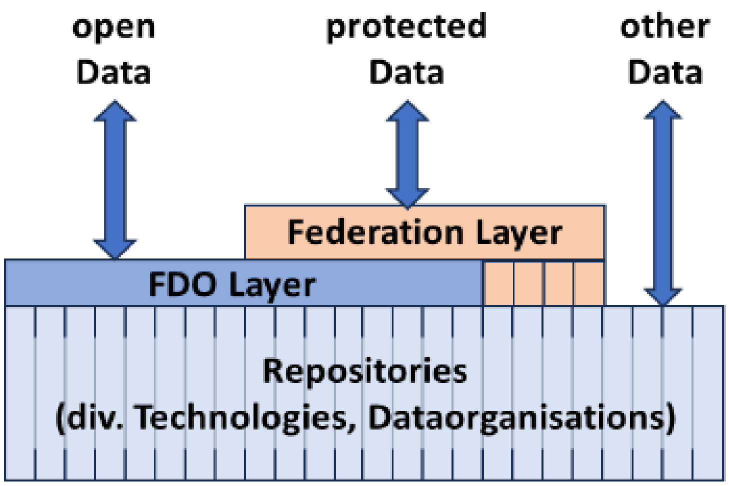

Figure 4 *schematically indicates the win-win situation for repositories using FDO as a generic standard. They simply need an adapter to be part of the global data net which will emerge and can offer all kinds of open data and metadata to users. In the case that they also want to offer protected data, they could make use of one FDO-EDC adapter to become part of a dataspaces defining specific reuse conditions.*

Let’s assume in the following that FDOs would be accepted as a global and basic interoperability standard and regard the EDC technology as a prominent example that allows to control the access and usage of data for which specific access conditions are needed. We could then describe the situation as indicated in Figure 4. Most repositories would accept FDOs as a generic standard and use it as a way to share open data and metadata. It should be noted that in almost all cases there will be some open metadata to inform anyone about the existence of a resource, however, in many cases some specific metadata might also be protected against unauthorized access. Others would use FDOs in connection with the EDC Dataspace layer where their access conditions can be defined using ODRL [23] and data access can flexibly be negotiated among parties. There will be repositories that will use other technology to control data reuse and there will be repositories that will not use FDOs as a generic standard due to specific needs.

The minimal design of FDOs ensures that it is simple to make control technologies, such as EDC, compatible. We demonstrate this with an FDO-EDC adapter that allows to publish datasets of an EDC component as FDOs. The adoption of FDOs by repositories that use EDC is therefore associated with minimal effort. It should be noted that we assume that a variety of countries and companies will develop their own technology for controlling the use of data to meet specific requirements.

When designing GIDS it makes sense to learn from the Internet success story and implement a layered architecture:

- First focus on a generic and simple exchange technology such as FDOs.
- Then apply an exchange control system such as EDC on top to allow access restrictions.
- More layers will be implemented to handle various applications that carry out operations on data.

As in the case of the Internet and the Web, the agreement on a core data model such as the FDOs would allow us to specify one simple interface protocol with help of which one can interact with FDOs independent of the data organisation and technology being used by the repositories. Repositories do not have to adapt their internal mechanisms; they simply would have to provide an adapter that allows the service provider to act to the outside world as if they were a FDO service providers.

3. FDO One Pillars

For the FDO One project the following first key pillars have been defined in order to showcase and promote basic elements for a realisation of the FDO concept:

1. Continue building the core infrastructural components based on what has already been started within EOSC and NFDI projects, make them available to interested parties, use them to build a first test environment and take actions to initiate an international testbed.
2. Carry out bridge building especially with technologies important for industrial dataspaces.
3. Start a standardisation roadmap process.
4. Study FDOs as active objects for autonomous processing.

There are a few other dimensions of the work such as organising meetings and doing dissemination which we will not discuss in this paper.

3.1 FDO Infrastructure and Testbed

3.1.1 FDO Infrastructure

The FDO Model [24,25] is on purpose simple as indicated in Figure 5. A PID (global unique resolvable persistent identifier) points to an FDO Record which contains a set of attribute-value pairs which may contain some metadata such as “type” and “checksum”, for example, but also contain references to the included data and various kinds of metadata (public, deep, annotations, rights, etc.). The FDO Record must comply with a registered FDO Profile that specifies the set of kernel attributes that are included. These kernel attributes need to be defined in open registries as well. The FDO Forum will specify a minimal set of kernel attributes as mandatory and define others as optional to increase interoperability. But it will also accept attributes that are defined by communities of practice. It should be noted that the “type” attribute is crucial since it will allow the invocation of procedures. This setup allows each FDO service provider to define its own FDO Profiles that may include domain-specific semantics. Being strict in these requirements implies that the FDO core machine is FAIR compliant and thus “machine actionable”. It should be noted that the specifications allow different implementations of FDOs.

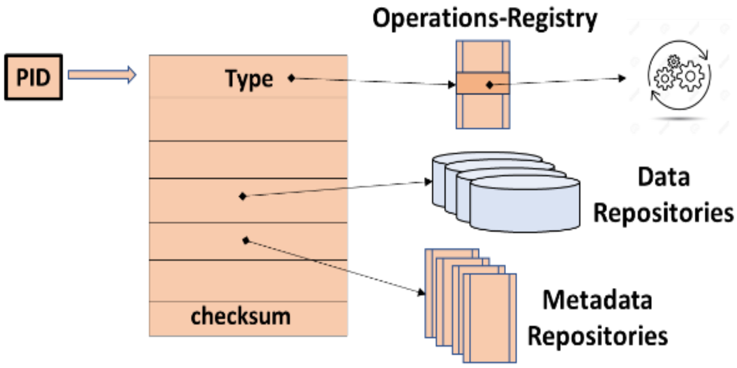

Figure 5 *indicates the core FDO model as specified by the FDO Forum: A PID points to an FDO Record which is fully specified by an FDO Profile. The FDO Profile holds relevant attributes which must be defined and registered to become “machine actionable”. Only a few attributes are mandatory.*

The basic FDO infrastructure therefore includes a PID registry, an FDO profile registry specified by the FDO Forum and a registry for kernel attributes that contain those defined by the FDO Forum. The testbed will also require a registry of repositories that are participating in the testbed. This simple core infrastructure needs to be set up such that

- everyone interested should be able to use it
- the user interfaces are simple
- it can be easily deployed at other centres to come to a distributed system
- there is at least one FDO repository that can be used by interested people
- there should be a portal showing the set of FDOs available in the domain which will be simple in the FDO One project

3.1.2 FDO Startup Testbed

We consider a testbed a platform for conducting rigorous, transparent, and replicable testing of scientific theories, computing tools, and new technologies. In the FDO One project a few first repositories will be integrated to an FDO domain by providing adapters. An FDO Manager [26,27] is being developed that allows to manipulate FDOs in these repositories which includes typical operations such as create, delete, copy, move, etc. It should be noted that some of these operations only require changes of the FDO Record, i.e., when for example the data of an FDO is being copied to another location, then additional references need to be added.

We foresee two types of ingestions which need to be supported by the basic infrastructure as indicated in Figure 6: (1) a known repository has additional FDOs that should be integrated which means especially to add their metadata to the portal. (2) A new repository adopts the FDO standard and makes its data available which requires in addition to verify that the repository adapter indeed fulfils the FDO specifications.

3.1.3 International FDO Testbed

The intention must be to test out all mechanisms in an international setting, i.e., test out cross-border aspects and scalability challenges, for example. FDO One therefore started discussions with several strong institutions worldwide to sign memoranda of understandings (MoU) with the intention to integrate their repositories and in doing so build a worldwide FDO domain. A few have already been signed. It has already been clarified that for the ramp-up phase training courses must be provided, synchronisation meetings need to be organised and a coordination board needs to be established. In parallel, the knowledge about efficiently developing adapters and validation procedures to check FDO compliance needs to be improved. It should be noted that FDO compliance does not include FAIR compliance of the data content stored in the repositories, however, a FAIRification plan is highly recommended.

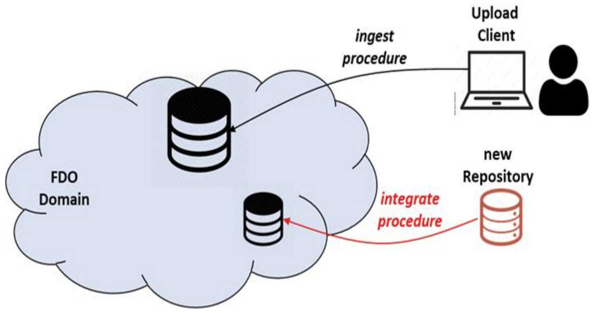

Figure 6 *indicates two typical ingestion types: (1) a known repository informs about new FDOs (ingest procedure) and (2) a new repository has adopted the FDO standard (integrate procedure).*

Four goals can already be identified for the “test operation” phase: (1) The core infrastructure should be deployed at other regional institutions to create redundance. (2) Core FDO applications need to be developed and deployed. (3) Scientific and/or industrial applications should be designed which also include protected data to not only test the usefulness of FDOs, but to also test out the bridges with usage control solutions such as EDC. (4) Integrate repositories that are using different implementation types of FDOs.

Given the different backgrounds and state of work of the participating repositories from the different regions we expect that organising the ramp-up phase will already cost some time and effort.

3.2 Bridgebuilding

An important pillar of FDO One is to test out bridge-building with technologies that have been worked out successfully in the realm of industrial interests. Here we want to mention two large initiatives: (1) The efforts of the IDSA [28] which resulted in the Eclipse Dataspace Connector technology and (2) the efforts within the I4.0 community [29] which resulted in the AAS technology. Both solutions will be presented briefly, for more details we refer to the references.

3.2.1 Eclipse Dataspace Connector Technology

The EDC technology was developed to be able to tightly control the usage of shared data according to agreed upon contracts and license conditions formalised as ODRL assertions. To achieve this control two connectors need to be installed – provider and consumer side, which then interact with each other and which interpret the ODRL assertions which have been defined by the producer. Of course some metadata can be exchanged with brokers which can for example create search portals etc. If procedures are going to be used to operate on the data, they can be taken from a jointly managed app store (see Figure 7). One should note that there are limitations for checking apps on correct behaviour. It is possible to carry out the usual checks on viruses etc. but when using large software packages as for example ML systems it is hardly impossible to control correct data usage.

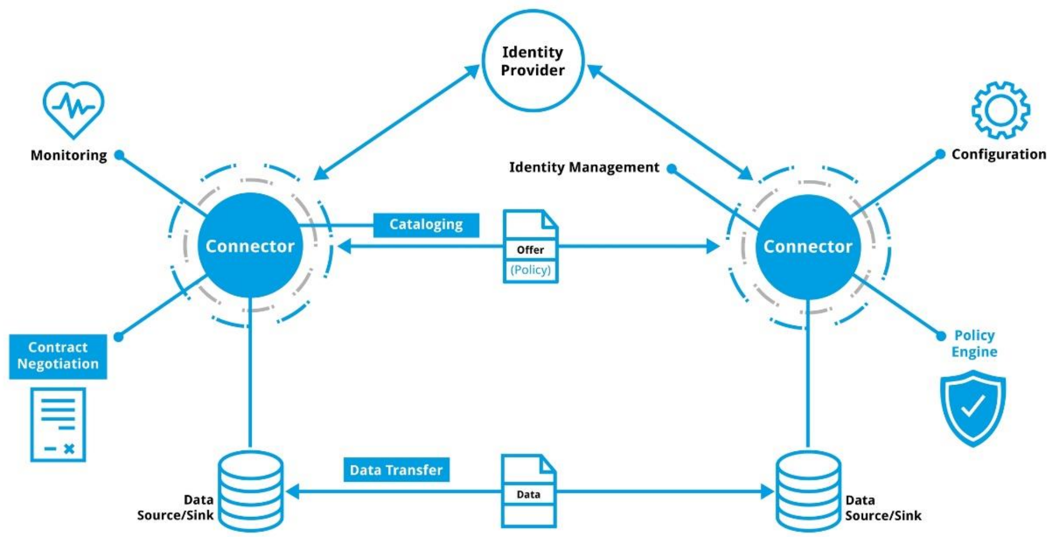

Figure 7 *is taken from the IDSA Reference Architecture and indicates how a secure data exchange can be realised using the Eclipse Data Connectors at provider and consumer side.*

Using EDC requires to set up a Dataspace with a strict governance to agree on many aspects such as roles of users who have certain rights, correct interpretation of the ODRL assertions, checks on using certified connector software, liaisons with accepted brokers, defining the set of joint apps that are allowed, etc. This technology is currently being tested out in some dataspace projects such as Mobility Data Space and Catena-X.

3.2.2 Asset Administration Shell

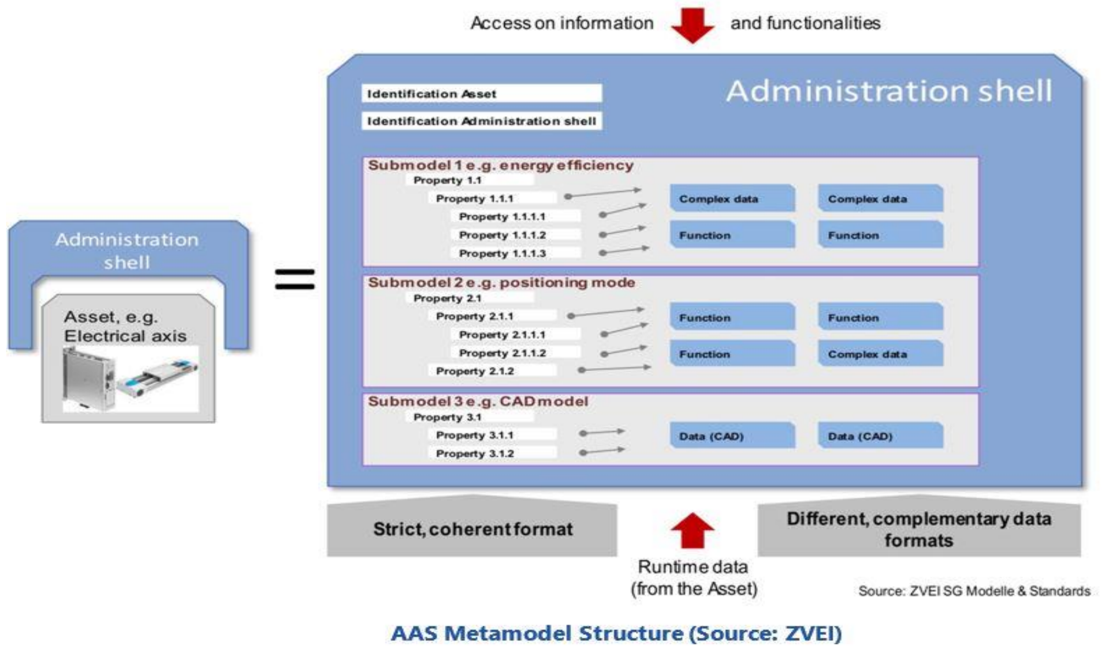

Figure 8 *indicates the component nature of the AAS model to describe assets in the required detail. It comes along with ready-made templates for specific modules, include semantics described elsewhere such as in eCLASS and provides a complete software stack for generation, management and access.*

I4.0 AAS was primarily developed as a flexible component-based metadata solution to describe physical machines and non-physical entities in all details. The developments include a complete software stack to create, store and maintain such metadata descriptions. In the meantime, it has been accepted as the basis of the International Digital Twin Association (IDTA) [30]. As indicated in Figure 8 it can be seen as a comprehensive and successful solution since it offers reusable templates for sub-module descriptions (Sub-module Templates) and collaborates with initiatives such as eCLASS [31], which is defining properties of technical systems to increase semantic interoperability, and interfaces to all its components and files being stored in company owned registries

I4.0 AAS was not primarily designed as a federation technology, however, I4.0 AAS is an excellent example of a comprehensive solution implementing dataspaces for specific purposes: Different producers participating in the development of complex machines, for example, contribute to their digital twins, store descriptions and references in secured registries and exchange protected information.

A GIDS approach will only be successful when many of such different already existing and emerging dataspaces are being considered and when attempts are being made to integrate them.

3.2.3 Bridge Building

The FDO One project is meant to demonstrate the feasibility of bridge building in so far as it should demonstrate that it is possible to interact with service providers that are included in dataspaces that use the EDC technology, such as the Mobility Dataspace, on one hand and service providers employing AAS models on the other hand. This is achieved in two steps:

1. repositories that cannot provide FDOs directly are equipped with an adapter that allows to expose data and metadata of the repository as FDOs
2. an FDO-EDC adapter allows to connect repositories that use the EDC technology without the need to modify the repository itself

A use case to demonstrate this integration is currently being set up as indicated in Figure 9. This demonstration will also show the feasibility of the layered model as indicated in Figure 4.

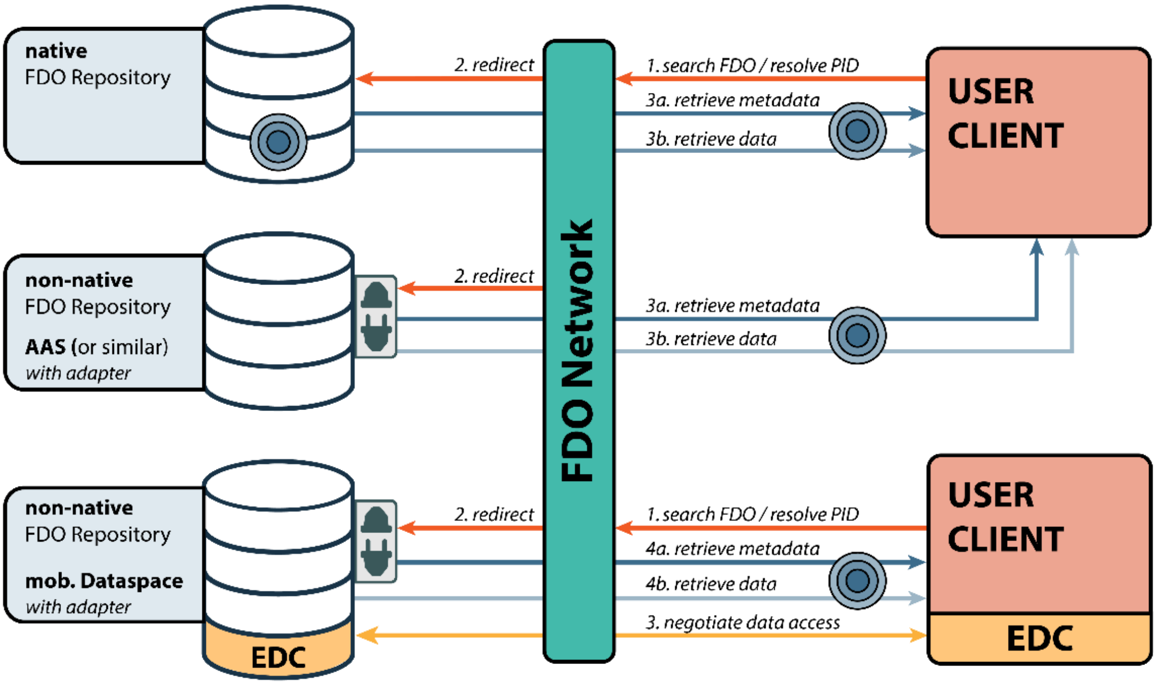

Figure 9 *illustrates how the FDO layer allows to interconnect clients and different repositories. In the top left an FDO repository is depicted that directly interacts with and offers FDOs (native). A user client, top right, can search an FDO or resolve the PID of an FDO and will be redirected by the FDO Network to the appropriate repository. If that repository serves FDOs and the data access is not restricted, the user can directly retrieve data and metadata of the FDO. A repository that does not use FDOs can be integrated by using an adapter that exposes datasets as FDOs. We demonstrate this for the case of an AAS Server that is integrated in the Testbed. It is possible to restrict the access to data by introducing EDC as an additional layer*

3.3 Standardisation

FDO One also wants to kick-off the standardisation work with respect to FDOs in collaboration with DIN/ISO. The basis for this work is the agreed collaboration between the FDO Forum and DIN, i.e., the FDO Forum is responsible for the specification work and FDO One fully adheres to these specifications. In this FDO One project we will kick-off the work on a standardisation roadmap and bring experts from FDO and DIN/ISO together. For the FDO Forum this is of great interest, since we expect already from early standardisation work comments on the specifications which will definitively help improving them. Furthermore, contacts with other experts working on related concepts will help to sharpen the intentions behind FDOs.

3.4 Invocation of Procedures

FDOs are not only passive units of information, they can be seen as active units that can include procedures. This feature of FDOs allows designers to build smart systems where FDOs communicate with each other in a secure and controlled way. A case study has been carried out to use this feature to implement the Digital Product Passport ecosystem, where different actors are all contributing to a shared document in a tightly controlled way ensuring that clearly identified actor types are only allowed to carry out specific operations on the shared document.

There are different ways to include such procedures which is currently being investigated within the FDO Forum with contributions from the FDO One project:

- Invocations can be included as values in the FDO Record which has some restrictions.
- Operations can be linked to FDOs by using an Operations Registry as indicated in Figure 5 where the FDO Type is used to identify suitable relations.
- Operations themselves can be FDOs described by metadata and a more complex match between FDO and Operations description could be used to identify useful operations.

It should be noted that the Operations Registry could be managed by the data owner/provider which allows providers to tightly control the type of usage of the data included in the FDO. This could for example be used by a hospital that has sensitive data and only wants to allow the calculation of some parameters on the data and their exchange using trusted software.

As has been indicated in diagram 7, the approach of EDC is to include an app store managed by the dataspace partners.

4. Conclusions

As the recent FDO implementation summit has shown there are already many projects funded partly within large programs mainly in Europe such as EOSC and NFDI and in the US implementing FDO technology as a basic entry level for data integration and interoperability [32]. The summit showed that there is also an increasing interest of other regions in a simple, open and FAIR-compliant technology which has the potential to integrate the many repositories and dataspaces out there all applying different regulations and technologies. The FDO One project is the first one which in its core addresses the FDO technology and where the work on globally relevant pillars (infrastructure and testbed, bridgebuilding with layered technology, standardisation, active FDOs) is being initiated.

The layered architecture chosen in FDO One is inspired by the Internet and Web success stories in so far as it advocates to use an open and simple technology, which is not addressing rights and ethics, in the basic layer and to use already accepted and powerful technologies addressing access control and asset modelling as motivated especially by industrial interests as layers on top. The FDO One project is working on a use case including different dataspaces to demonstrate the usefulness of such a layered approach for realising the Global Integrated DataSpace, but it is meant to show feasibility of the bridgebuilding. The same is true for the other important pillars. It needs to kick-off building an international testbed, start with a standardisation roadmap and start studying the opportunities of active FDOs. Projects with a core focus on FDOs, which should be funded for a longer period, should ensure a broader impact.

The FDO One project is a crucial and basic element of the Mission AI program which is meant to foster the Data Economy, since it will a) facilitate access to more and better data by creating a common interoperability layer, b) facilitate access to data across sector and country borders by implementing an interoperability layer which shifts addressing special requirements to upper layers, c) bridge between the many existing and emerging dataspaces all applying different regulations and technologies, d) kick-off a standardisation process resulting in trust, and e) support dissemination through trainings and by networking with experts worldwide.

Data availability statement

There is no data included in this paper.

Author contributions

All authors work on the FDO One project and were involved in the writing.

Competing interests

The authors declare that they have no competing interests.

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