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A Values-Driven Cyber-Farm of Trigram Metaverse Based on Autonomic Crowd-Dispatching

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ABSTRACT

The objective of this work is to apply cutting-edge digital techniques to address several identified essential problems, from which farmers, farming, and farms have suffered for centuries. It has been found that the participants in the metaverse-related agricultural applications have been designed to be users rather than residents. There is another critical setback for the metaverse to be a fusion cyber-physical space, in which the cyber space is subject to different values principles from the physical space. A trigram metaverse of Cyber-Farm is proposed to be constructed on a unified trigram space through the fusion of cyber, physical, and values spaces. As a parallel and superstructure to the cyber and physical spaces, the values space enables the cyber space and physical space to follow the same values principles through its autonomic, values-driven, and crowd-dispatching governance system. Unlike in the existing metaverse-related agricultural applications, the Cyber-Farm participants are the subjects/residents rather than the users of a Cyber-Farm. The agricultural elements are coming into being and evolving in the interlinked and fusion trigram space. The basic production means, production relations, and superstructure of the trigram metaverse have been discussed. Both the connotations and scopes of farm, farmer, and farming have been redefined in the trigram metaverse of Cyber-Farm. The intentions, scenarios, principles, and businesses of the Cyber-Farm have been restructured. Basically, the Cyber-Farm can address the identified essential problems with today's agriculture, while a grand vision is to bring about farm-featured Utopias parallel to human communities.

KEYWORDS

metaverse; digital agriculture; cyber space; digital twin; crowd intelligence science

The essential agricultural problems have not been addressed by metaverse-related agricultural applications such as games, virtual reality, and online planting applications. As the capabilities of our eyes, ears, noses, feet, and brain have been dramatically extended by metaverse techniques, this work is to apply the cutting-edge techniques to make an autonomic Cyber-Farm. The Cyber-Farm is operated in a trigram metaverse, which is constructed on a consistent trigram space model with fusion of cyber, physical, and values spaces. All the agricultural elements are coming into being in an interlinked and fusion space with the trigram space. The values space is proposed to be a parallel and superstructure to the cyber and physical spaces, and governs the two spaces with the same value principles (as a part of Tao principles). In the context of Cyber-Farm, the participants are the internal subjects/residents rather than the users of the farm. A blockchain-based data infrastructure, a whole-benefit-oriented crowd computing, a rule-based dispatching engine, and contract-based public services are operating in the values space to make autonomic governance. The proposed Cyber-Farm can be expected to address the identified essential problems with agriculture, while a grand vision is to bring about farm-featured Utopias parallel to human communities.

The rest of this article is organized as follows to systematically present the Cyber-Farm metaverse. Section 1 identifies several essential problems across agricultural innovation, research, breeding, trading, consuming, and governance, from which farmers, farming, and farms have suffered for centuries. A critical setback of the metaverse-related agricultural applications is also identified. Based on the identified critical setback and essential agricultural problems, Section 2 introduces the objectives, scenario, architecture, and elements of the Cyber-Farm, and discusses the basic production means, production relations, and superstructure of the trigram metaverse. With the principles and features, Section 3 discusses the resolutions to the essential agricultural problems, and the critical and special supporting technologies to implement a Cyber-Farm. Following the principles and techniques, Section 4 provides an initial software framework of Cyber-Farm implementation, and a conceptual prototype is presented to demonstrate a number of Cyber-Farm concepts, with major findings through development. Section 5 concludes the work.

1 Motivation and Related Work

1.1 Motivation

In the following, a number of essential issues, from which farmers, farming, and farms have suffered for centuries, have been identified across agricultural innovation, research, producing/breeding, trading, consuming, and governance.

(1) Identified issues with farmers

There are three critical issues with farmers, which impact today's agriculture, namely, (a) lack of agricultural knowledge, (b) narrow and limited income, and (c) low-level pursuit for survival.

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(2) Identified issues with farming

● There are three critical issues with agricultural innovations and researches, which impact today's farm development, namely, (a) lack of breakthrough ideas for new breeds or businesses, (b) lack of collaboration among dispersed agricultural institutions, and (c) low-level application of digital simulation into crop breeding.

● There are three critical issues with agricultural production and outputs, which impact today's farms, namely, (a) labor-intensive farming, (b) small-sized and inefficient farms, and (c) vulnerable to disasters.

● There are three critical issues with agricultural circulation, which impact today's agricultural market and green sustainable development, namely, (a) single use value of agricultural products, (b) higher trading cost by low creditworthiness, and (c) higher waste because of imbalance between supply and demand.

● There are three critical issues with agricultural consumption, which impact today's green sustainable development, namely, (a) high loss by food storage, (b) unhealthy cooking, and (c) low recycling of agricultural products.

(3) Identified issues with farms

There are three critical issues with today's farms, which impact agricultural industry development, namely, (a) lack of qualified production personnel, (b) unbalanced resource allocation, and (c) difficult in coordinating production and circulation.

1.2 Related work

There are several metaverse-related applications and technologies emerging in agriculture, such as those of agricultural metaverse[1–3], digital farms[4–6], social games of farms[7,8], and Internet of Things (IoT) and cloud-based smart agriculture[9–11]. Involved in the applications are the virtual reality techniques such as plant modelling and simulation[12–15], cyber-physical interaction[16–18], digital twins[19,20], crowd computing[21–23], non-fungible tokens[24–26], digital money[27,28], and community management[29,30].

There is a critical setback with the investigated metaverse-related agricultural applications to interlink the cyber space with the physical space. That is, all the applications design their players as the users rather than residents. As a result, the users are naturally separated and detached from the applications, while the cyber space is independent of the physical space. The cyber space is subject to different values principles from the physical space. The fusion between the two spaces is limited to interactive interlinks. The involved agricultural elements cannot be elaborated as a whole unit as well as in a physical farm.

There are not related literature found to discuss the specified production means, production relations, and superstructure of the metaverse, which interlink the physical and cyber spaces to be a uniform space. Neither are there discussions found on the predefined social systems and principles, which distinguish a specified space, and make differences between the physical space, cyber space, and cyber-physical space.

2 Principle and Concept

2.1 Objective

The basic vision of this work is to propose a Cyber-Farm of trigram metaverse, which is values-driven and autonomic agricultural community to make the best use of talents, resources, and fair distribution. The basic production relations of the Cyber-Farm of trigram metaverse is proposed to be "on-demand organizing, crowd-collaborating, and values-driven contracting". Its superstructure is "values-based autonomic governance". The governance system can assure both the physical and cyber spaces follow the same values principles, and all the valuable agricultural activities can be accomplished by right subjects, at right time, with right schemes.

All the production means, production relations, and superstructure of the trigram metaverse will be discussed. A number of essential agricultural issues, from which farmers, farming, and farms have suffered for centuries, will be addressed by exploiting a number of cutting-edge digital techniques. All the connotations and scopes of farm, farmer, and farming will be redefined. The intentions, scenarios, principles, and businesses of the Cyber-Farm are to be restructured. In a Cyber-Farm, farmers are equal and with no any discrimination at identity and disability, farms are smart and green, and farming activities are crowd intelligent and collaborative. Theoretically, a potential grand vision is to bring about farm-featured Utopias parallel to human communities.

2.2 Scenario

As shown in Fig. 1, the subjects, objects, resources, services, and activities are Cyber-Farm elements in an interlinked cyber-physical space. The subjects are the participants in the Cyber-Farm activities or services. The objects include both the cyber and physical objects, which involved in the activities or services. The resources include both the cyber and physical resources, which involved in the activities or services. The services include both the cyber and physical services, in which the Cyber-Farm subjects, objects, and resources involved. The activities include both the cyber and physical activities, such as agricultural innovation, research, producing/breeding, trading, and consuming, in which the Cyber-Farm subjects, objects, and resources involved. Further in the values space of a Cyber-Farm are there data infrastructure, value-driven specifications, crowd computing, dispatcher, and operation services. Among the operation services, operation specifications are those for subjects/objects/resources/services/activities/security/environment, supporting services, public services, and administration services, which provide a

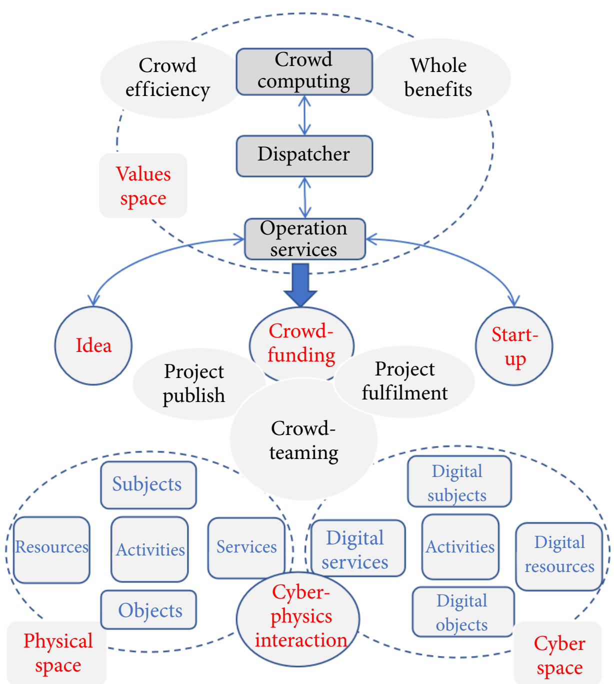

Fig. 1 A plant breeding activity in the Cyber-Farm.

superstructure to govern the Cyber-Farm.

Also illustrated by Fig. 1 is a typical use example, in which an activity “crowd-funding” is presented as an example of Cyber-Farm activity to illustrate the basic vision of the Cyber-Farm. Among the Cyber-Farm elements are the subjects (A/B/C/D and their digital twins A'/B'/C'/D'), objects (triangle plums and their digital twins), resources (farmland and their digital twins), services (crowd-funding), activities (plant breeding), crowd-computing, dispatcher, and operation services. The basic processes of the activity are presented as follows:

(1) **Idea.** A is a blossom hobbyist and has a digital twin A' in a Cyber-Farm. Occasionally he gets a start-up idea to breed a triangle plum by grafting from osmanthus.

(2) **Project publish.** A' comes to a crowd-funding service, one of the operation services by the Cyber-Farm, to publish a crowd-funding project for start-up partners with breeding know-how, skills, funding, and operation.

(3) **Crowd-teaming.** The dispatcher is invoked to conduct an evaluation service with partner match-making on a predefined crowd-breeding model. The potential partners are discovered and notified. A best-fit start-up team are made from those with positive responses. With a multi-bidding scheme, among the team are a funding partner B', a grafting professional C', a grafting artisan D', and a plantation owner E'.

(4) **Project fulfillment.** The crowd-funding service operates the project fulfillment with autonomic crowd computing and dispatching. With the funding by B', C' evaluates the graft idea (possibly through plant breeding simulation tool, a native service in the Cyber-Farm). If the professional evaluation result is positive, D/D' and E/E' conduct grafting, with grafting activities being consistent between the cyber and physical spaces.

(5) **Business start-up.** In the case that the idea has been testified and recognized through both theoretical and practical evaluation, the crowd-funding service continues with start-up team service, including further funding, marketing, and operating dispatching.

Note 1: Across the project fulfillment, the involved plants and plantation are required to be present both physically and digitally.

Note 2: Crowd computing for the dispatcher is with both crowd efficiency and whole benefits. The physical entity and digital entity of the same partner have different contributions at efficiency and benefits, and are different candidates for partners' dispatching.

2.3 Architecture of the Cyber-Farm

The Cyber-Farm metaverse is an independent agricultural community in nature as well as an agricultural ecosystem based on Web 3.0 infrastructure. It is built on a fusion trigram space of cyber, physical, and values spaces. A values-oriented governance system is developed as an entity or “resident” in the values space. The system is to realize the vision of the Cyber-Farm, namely, an autonomic, trustworthy, fair, smart, efficient, and green agricultural unit.

The Cyber-Farm is a values-driven metaverse based on autonomic crowd-dispatching. As can be seen in Fig. 2, a Cyber-Farm is composed of a physical space, a cyber space, and a values space, all of which are unified to be a trigram space by fusion. The cyber space is interlinked with the physical space with two-way interactive linkages. Both the cyber and physical spaces are driven and governed through the operation services from the values space.

2.4 Concept of the Cyber-Farm

(1) Cyber-physical-values trigram space

As illustrated in Fig. 3, the Cyber-Farm of trigram metaverse is constructed on a unified trigram space model through the fusion

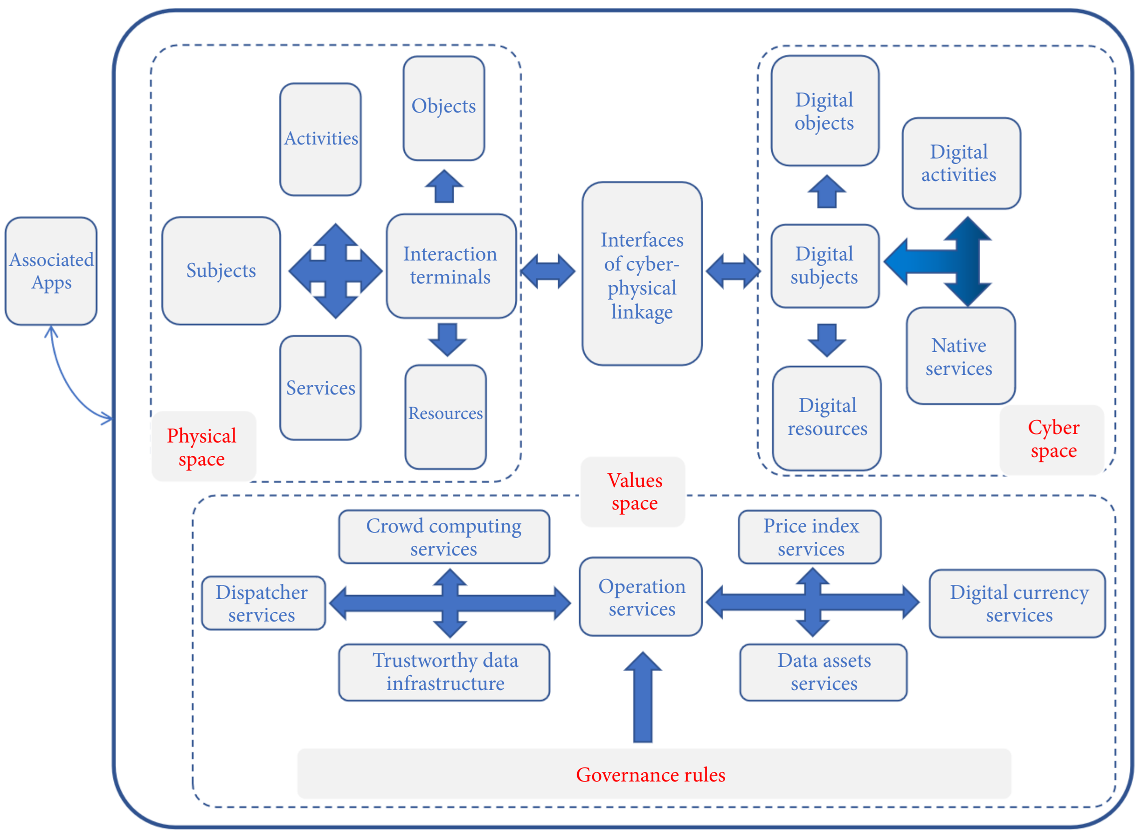

Fig. 2 Architecture of the Cyber-Farm.

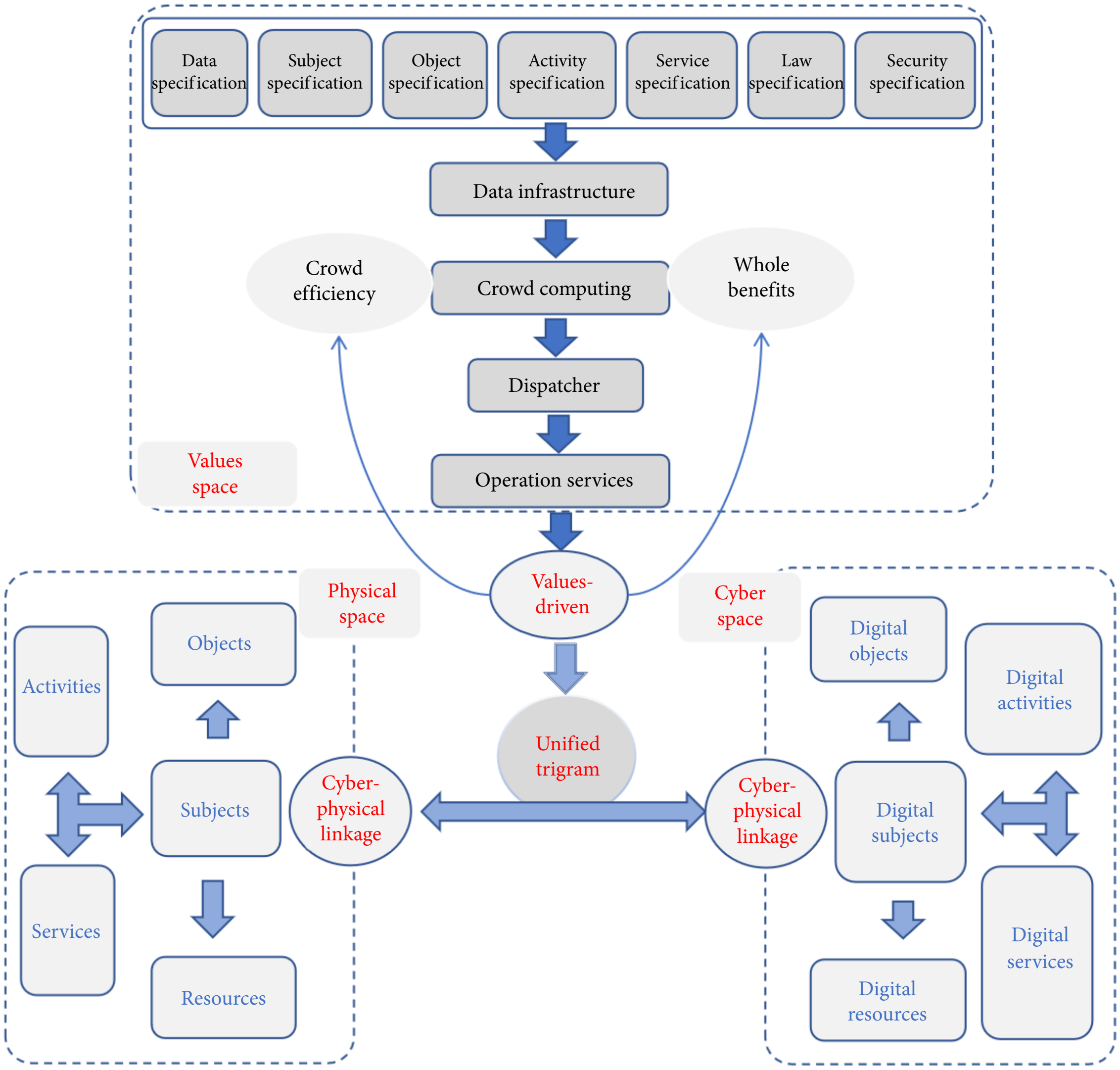

Fig. 3　Trigram model for Cyber-Farm governance and operation.

of cyber, physical, and values spaces. All the Cyber-Farm elements are coming into being and evolving in the unified trigram space. Both the cyber space and physical space are interlinked to be a unified space. The values space is a parallel and superstructure to both the cyber and physical spaces. From the viewpoint of farming community, it is through an independent values space that both the cyber and physical elements follow the same farming-related values principles to be deeply unified and fusion. Basically, data infrastructure, value-driven specifications, crowd computing, dispatcher, and operation services are developed in the values space.

(2) Cyber-physical space

With two-way interactive linkages, the cyber space is interlinked with the physical space to be a cyber-physical fusion space. Basically, the involved entities are subjects, objects, resources, services, and activities, which are developed in the context of cyber-physical fusion space. All of them are equivalent to each other whether in the physical space or cyber space. Further in the space, subjects are diverse and equivalent, objects are distributed and cross domain, and activities are integrated across the metaverse.

(3) Values space and governance system

The basic production relations of the Cyber-Farm of trigram metaverse is defined as "on-demand organizing, crowd-collaborating, and values-driven contracting". As illustrated in Fig. 4, the Cyber-Farm is operated based on values-driven governance. To make a trustworthy, fair, efficient, green, and collaborative community, the Cyber-Farm is developed with an autonomic governance system, which is the basic entity or "resident" in the values space. A collection of public specifications is developed to incorporate the value properties and orientation of all the farm subjects, objects, resources, activities, and services. A blockchain-based data infrastructure, a whole-benefit-oriented crowd computing，a rule-based dispatching engine, and contract-based public operation services are running in the values space to make value-driven and rule-based governance.

(4) Subject

The subjects are the participants in the Cyber-Farm activities or services. Unlike in the existing metaverse-related agricultural applications, the Cyber-Farm participants are the subjects rather than the users of the Cyber-Farm in the unified trigram space of the Cyber-Farm.

As shown in Fig. 5, among the subjects are institutions, individuals and associated digital twin subjects, service-oriented associate subjects, and digital native subjects. The counterparts of the subjects between cyber and physical spaces are ruled by a specification, which is developed for the Cyber-Farm case by case.

Any subject with predefined credit is allow to join a Cyber-

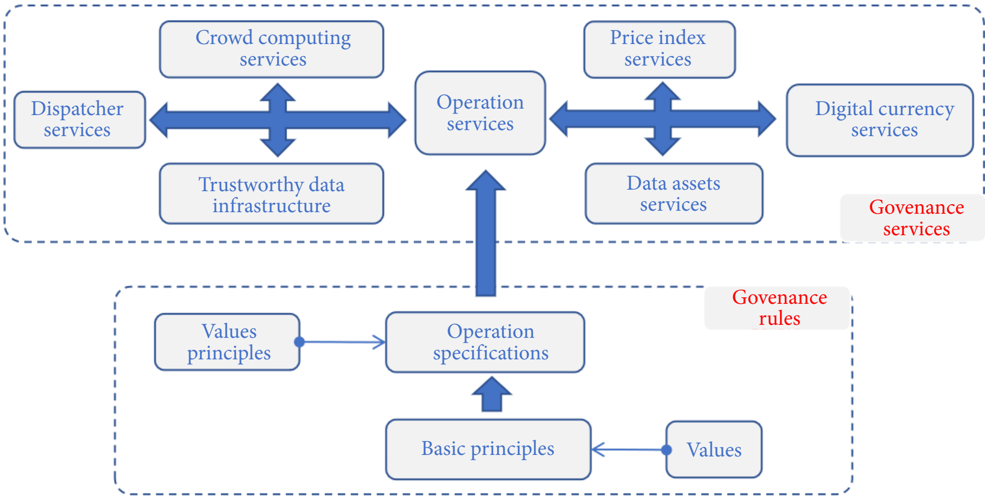

Fig. 4 Governance model for Cyber-Farm.

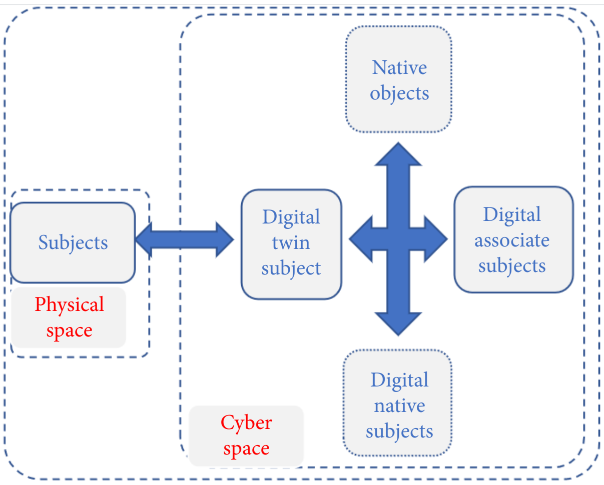

Fig. 5 Subjects of a Cyber-Farm.

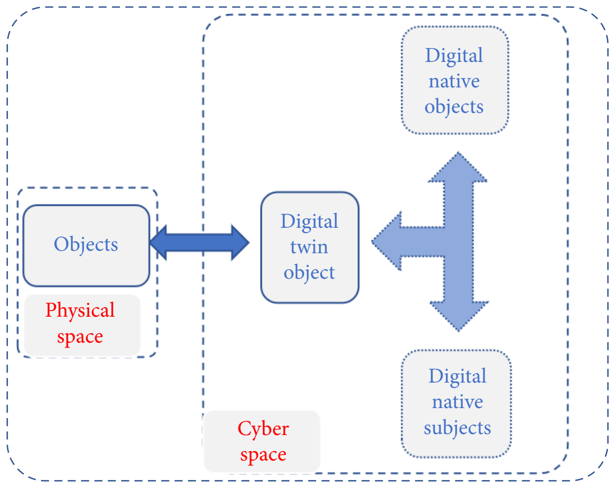

Fig. 6 Digital objects of a Cyber-Farm.

Farm no matter where and what they are, retired or at post, full-time or part-time, disable or healthy. To implement this nondiscrimination policy, the characteristic properties are developed to be consistent between the physical and cyber subjects, while the appearance or health status can be inconsistent.

(5) Object

The Cyber-Farm objects include both the cyber and physical objects, which involved in the activities or services. Among the objects are crops, plants, fishes, livestock, and their products. As shown in Fig. 6, the cyber objects could be physical objects-associated digital twin objects or native objects. The counterparts of the object between cyber and physical spaces are ruled by a specification, which is developed for the Cyber-Farm case by case.

Objects can join a Cyber-Farm from different districts and owners. They are distributed in physical space while organized in cyber space. Both the physical and biological properties of the objects are developed to be consistent between the physical and cyber spaces, while the resettlement and appearance can be inconsistent on demand.

(6) Resource

The resources are among the basic Cyber-Farm production means. The Cyber-Farm resources include both the cyber and physical resources, which involved in the activities or services. Among the resources are farmlands, rivers/pools/ponds/seas, and cattle pens. As shown in Fig. 7, the cyber resources could be physical resources-associated digital twin resources or native resources. The counterparts of the resources between cyber and physical spaces are ruled by a specification, which is developed for the Cyber-Farm case by case.

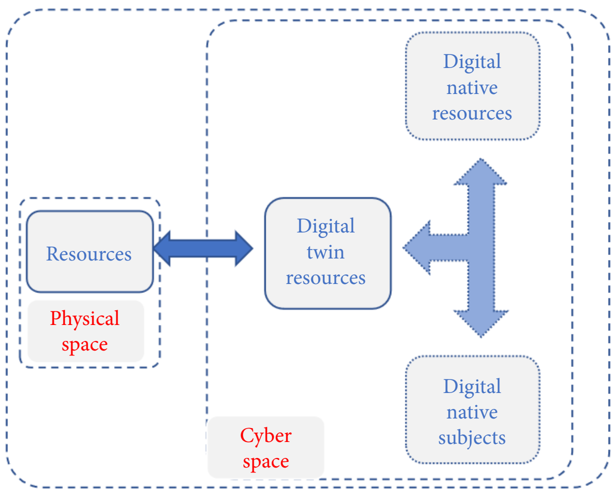

Fig. 7 Digital resources of a Cyber-Farm.

Resources can join a Cyber-Farm from different districts and owners. They are distributed in physical space while organized in cyber space. Both the physical and biological properties of the resources are developed to be consistent between the physical and cyber spaces, while the resettlement and appearance can be inconsistent on demand.

(7) Service

The services are another type of basic Cyber-Farm production means. The Cyber-Farm services include both the cyber and physical services, in which the Cyber-Farm subjects, objects, and resources involved. Among the services are knowledge, farming, business, or cultural services. Besides the services provided in the physical space, there are two types of digital services in the cyber space of a Cyber-Farm. The one type of digital services are initiated and provided from cyber space. The other type of digital services are the copies of the physical services. The services can be operated in their native space or cross the space, and the involved subjects, objects, and resources can be from the cyber or physical space. The services are ruled by a specification, which is developed for the Cyber-Farm case by case.

(8) Activity

The Cyber-Farm activities include both the cyber and physical activities, in which the Cyber-Farm subjects, objects, and resources involved. Among the activities are farming, social, or cultural events. Besides the activities provided in the physical space, there are two types of digital activities in the cyber space of a Cyber-Farm. The one type of digital activities are initiated and provided from cyber space. The other type of digital activities are the copies of the physical activities. The activities can be operated in their native space or cross the space, and the involved subjects, objects, and resources can be from the cyber or physical space. The activities are ruled by a specification, which is developed for the Cyber-Farm case by case.

3 Resolution and Critical Supporting Technique

3.1 Resolution to the farmers, farming, and farm issues

In the context of Cyber-Farm, a number of cutting-edge digital techniques are exploited to address the essential agricultural issues, from which farmers, farming, and farms have suffered for centuries. Both the resolutions and expected outcomes are discussed in the following.

(1) Resolution to the identified issues with farmers

It is in the context of cyber-physical-values fusion space of the Cyber-Farm, the mentioned three issues with farmers can be addressed simply by an open policy to attract all the potential farmers to join, with no any limitation at identity, disability, employment, part-time, profession, area, or region. This function is easy to realize through virtual/augmented/mixed reality, and operations. It is expected that Cyber-Farm participants or farmers (a) could be various people with professional knowledge and skills, (b) get incomes from as many farming services, like planting and consulting services, as they can provide, which are far beyond single crops yields, and (c) may work for recreation, entertainment, and pleasure than survival.

(2) Resolution to the identified issues with farming

In the context of cyber-physical-values fusion space of the Cyber-Farm, the three issues with agricultural innovations and researches can be addressed by applying crowd-funding, crowd-research, and digital simulation with aggregated resources. It is expected that crowd computing, digital twin, and virtual/augmented/mixed reality can improve Cyber-Farm researches to be driven by (a) real requirements and risk pooling by multi-subjects, (b) smart response and collaborative program, and (c) efficient iteration with fusion of cyber-physical-values.

The three issues with agricultural production and outputs can be addressed by applying the digital twin, IoTs, and artificial intelligence techniques to develop smart/virtual/precise farming, integrated production and management of distributed farms, and flexible green insurances on demand. It is expected that Cyber-Farm production and outputs could be (a) smart and cyber-physical interlinked, (b) economy of scale on aggregation of small farms, and (c) robust and risk-resistant at disasters.

The three issues with agricultural circulation can be addressed by applying the techniques of crowd computing, blockchain, big data, and artificial intelligence to develop the services of digital assets, creditworthiness, and precise dispatching. It is expected that Cyber-Farm circulation could (a) make value-added hobby, recreation, or collection services for more values across the agricultural life-cycle, (b) develop the creditworthy, traceable, and precise direct sales to reduce brokers that do not produce use values, and (c) develop precise dispatching engine to leverage the supply and demand and reduce waste.

In the context of cyber-physical-values fusion space of the Cyber-Farm, the three issues with agricultural consumption can be addressed by applying the techniques of IoTs, secure computing, and big data to develop the services of food expiration warning, healthy cooking, and recycling. It is expected that Cyber-Farm consumption could use the cyber-physical-interlinked consumption services to (a) reduce the loss by food expiration, (b) make healthy food follow the personalized suggestions, and (c) improve the recycling ratio of agricultural products.

(3) Resolution to the identified issues with farms

In the context of cyber-physical-values fusion space of the Cyber-Farm, the three issues with today's farms can be addressed by applying the techniques of trusted blockchain, crowd computing, big data, and artificial intelligence to develop the services of trusted data infrastructure, crowd-collaborating, and precise dispatching. It is expected that the Cyber-Farm could apply the cyber-physical-values fusion model to (a) implement fair and right distribution based on contributions to attract more qualifies personnel, (b) develop accurate dispatching of resources to make fair and efficient allocation, and (c) develop timely and precise coordination between production and circulation, and implement green agriculture with as little waste as possible.

3.2 Critical supporting techniques of the Cyber-Farm

(1) Identification of critical supporting techniques

The Cyber-Farm is a values-driven trigram metaverse. Therefore, all the meter-verse-related cutting-edge techniques are useful to develop the Cyber-Farm, which are published in many works and should not be presented in this article.

In the context of Cyber-Farm, the critical supporting techniques are those specially for realizing the special features of Cyber-Farm. As mentioned, the Cyber-Farm of trigram metaverse is built on a fusion trigram space of cyber, physical, and values spaces. Its vision is to be a highly autonomic, trustworthy, fair, smart, efficient, and green agricultural unit. A values-oriented governance system is developed as a resident of the values space to realize the vision. And all the Cyber-Farm services and activities are processed with crowd-dispatching.

The above features make the Cyber-Farm be a highly hybrid space rather than a traditional metaverse. To tackle the raised challenges by the special visions and features, there are a number of special critical techniques to be developed. Among them are the autonomic and trusted data infrastructure for Cyber-Farm, the crowd computing and collaboration dispatching based on values and gains, the cyber-physical interactive techniques for Cyber-Farm, the values-oriented digital subject models based on digital human techniques, and the value-oriented digital model of a twin/native object/resources.

(2) Autonomic and trusted data infrastructure for Cyber-Farm

An blockchain-based data infrastructure is critical for a Cyber-Farm. Both the values space and cyber space, and their elements are operating on the infrastructure to ensure that the Cyber-Farm is autonomic and trusted. As shown in Fig. 8, it is through a combination of blockchain and data repository to store the Cyber-Farm data. That is, all the Cyber-Farm data are stored in the data repository, while the copies of critical data are upload in the blockchain for possible tracing or testifying. Smart contracts are developed to support governance services of the Cyber-Farm. Further, a secure multi-party computation service is critical for the hybrid entities to share their data with enhanced privacy protection.

(3) Crowd computing and collaboration dispatching based on values and gains

The Cyber-Farm is driven by governance services in the values space, which is a parallel and superstructure to both the physical and cyber spaces, and makes the Cyber-Farm value-driven and rule-based governance. As illustrated in Fig. 9, behind the governance services is a rule-based dispatcher. The dispatcher is supported by a crowd computing service. At the same time, "Obtained by Contribution" is a right, fair, and well-acknowledged values around the world. The values should be followed by the crowd computing service to drive the Cyber-Farm. To implement a values-driven crowd computing model, all the nodes of crowd network should have a value and gain of assessment. For value of assessment, all the involved values, such as use value, collection value, recreation value, knowledge, skills, or whatever could contribute, should be counted. For gain of assessment, all the raised gains, such as incomes, pleasure, assets, indirect earnings, or whatever could benefit, should be counted. Further, there are two more nodes of "environment" and "community" that should participate in any activity or service when developing the crowd network. With the comprehensive consideration, a whole-benefit-oriented crowd computing model and service can be implemented.

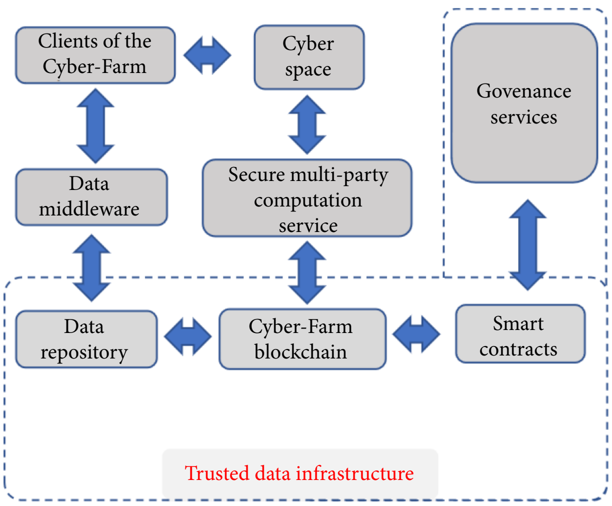

Fig. 8 Trusted data infrastructure based on Cyber-Farm blockchain.

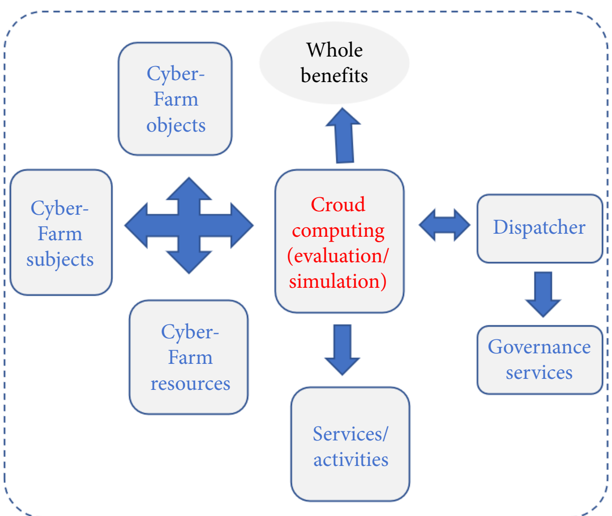

Fig. 9 Crowd computing model of Cyber-Farm.

(4) Cyber-physical interactive techniques for Cyber-Farm

It is with two-way interactive linkages, the cyber space is interlinked with the physical space to be a cyber-physical fusion space. As shown in Fig. 10, the subjects interact with their digital counterparts through user terminals. Both the objects and resources' status are consistent with their digital counterparts through IoTs equipment. And the services and activities are processed across the cyber-physical fusion space through predefined processes. Such a fusion space with hybrid elements provides big challenges at developing interactive models. The techniques of human-centered interaction, IoTs sensing and controlling, and cyber-physical fusion processing should be developed to make the Cyber-Farm realized.

(5) Values-oriented digital subject models based on digital human techniques

As mentioned, the cyber space of a Cyber-Farm hosts digital twin subjects, service-oriented associate subjects, and digital native subjects. All of the three digital subjects are basic and critical for a Cyber-Farm. The cutting-edge techniques of digital human techniques should be applied to model the subjects. As illustrated in Fig. 11, all the digital twin/associate/native subjects can be developed in the same model. Among the basic elements of the model are anima (natural character), behaviors, and appearance. Both the behavior and appearance may follow the popular digital human techniques of augmented reality and 3-dimensional modelling.

In the context of values-driven Cyber-Farm, the digital subjects should reflect the values of the subjects. It is reasonable to choose the character-oriented human modeling techniques. Anima can be developed with reference to the author's previous work, in which a concept of Cyber-A(nima) is proposed to reflect the nature of an individual person (or any individual entity) with inner humanity concepts of physiology, belief, character, knowledge, and experience[20]. The anima is driving and transformed from outward personal behaviors, interests, and appearances, which are collected as big data of Cyber-Farm and from user inputs, Wikipedia, application systems, and portable equipment. Service-oriented and role-based subject models can be further developed from Cyber-A(nima)[20].

Further to realize the values of subject nondiscrimination, the anima (natural character) properties are developed to be consistent between the physical and digital subjects, while the appearance and behavior are not required to be consistent or complete.

(6) Value-oriented digital model of a twin/native object/resources

As mentioned, the cyber space of a Cyber-Farm hosts digital twin/native object/resources, which are essential entities of a Cyber-Farm. The cutting-edge techniques of 3D, virtual reality, and object information model should be exploited to model the subjects. As illustrated in Fig. 12, both the digital twin/native

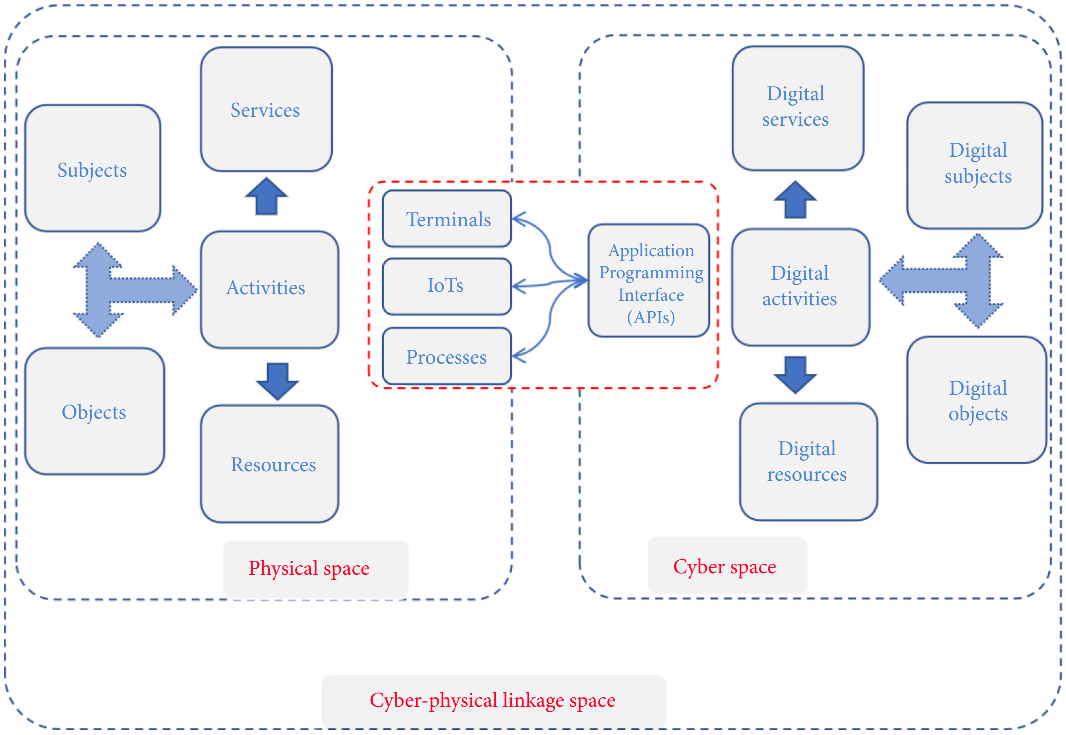

Fig. 10 Cyber-physical interaction in a Cyber-Farm.

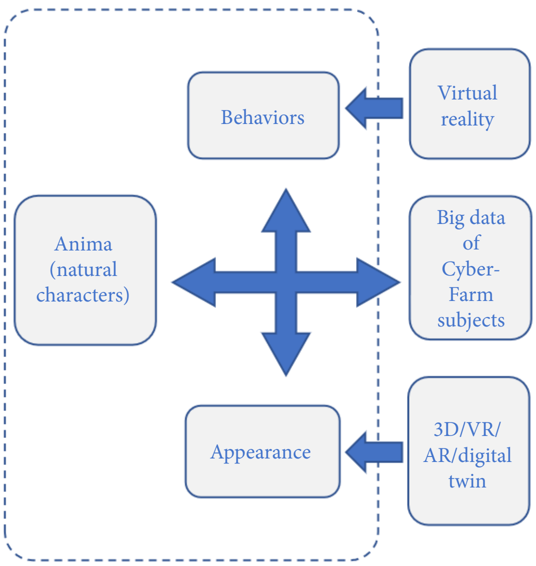

Fig. 11 Digital model of a twin/associate/native subject.

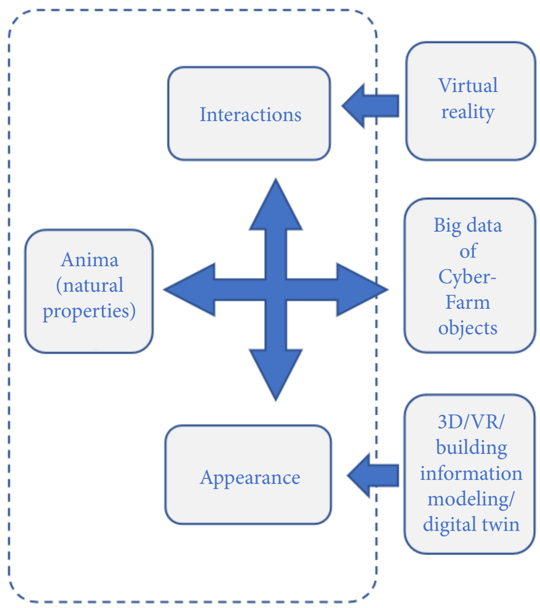

Fig. 12 Digital model of a twin/native object/resource.

objects can be developed in the same model. Among the basic elements of the model are anima (natural properties), interactions, and appearance. Both the interactions and appearance may follow the popular techniques of 3D, virtual reality, digital twin, and object information model. However, to realize the value-driven governance principle of the Cyber-Farm, it is required to incorporate the natural properties of the objects/resources for comprehensive value of assessment.

The anima (natural properties) can also be developed with reference to the concept of Cyber-A(nima), which was presented in a previous work by Li et al.[20] As mentioned, the paradigm of Cyber-A(nima) is to reflect the nature of an individual person (or any individual entity) with inner properties, which are independent of the surroundings, stay consistent, and drive the interactions and appearances of the objects/resources. In comparison with the subjects, the natural properties of objects/resources are associated with their physical, chemical, and biological features. Beside the primitive natural properties, further properties should be developed oriented to support specified farm scenarios such as crops/plants/fishes/animals breeding, production, and consumption.

4 Implementation Framework of the Cyber-Farm

4.1 Software structure of the Cyber-Farm

The Cyber-Farm of trigram metaverse is a Web 3.0 application. The software is the major application development. As shown in Fig. 13, a number of software components are developed to be a

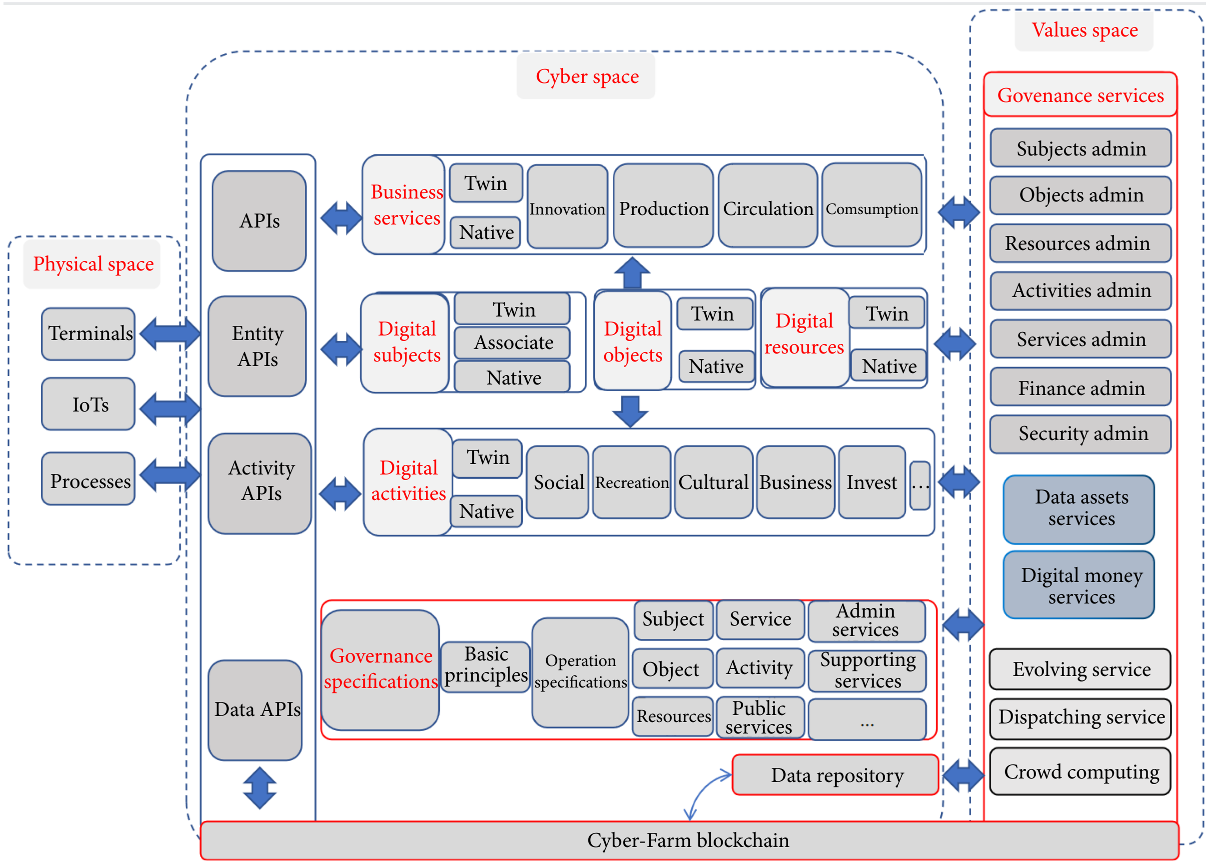

Fig. 13 Software structure of the Cyber-Farm.

start-up scheme for a Cyber-Farm metaverse. There are software components to carry each space of the trigram. That is, all the software of terminals, IoTs, and processes are in physical space, while the digital subjects/objects/resources/services/activities, and their interactive APIs are located in the cyber space. The governance specifications, blockchain, data repository, and governance services are located in the values space. The brief introduction of the software components is as follows.

4.2 Description of the components

(1) Interactive components in the physical space

The terminals, IoTs, and processes are in physical space. The user terminals could be mobiles, computers, or portable equipment. Their functions are to support physical subjects' operations. The functions of IoTs are to collect the status data of the physical objects and resources, and control them. The processes are to interact with physical subjects to execute the services or activities.

(2) Components in the cyber space

(a) Interactive components in the cyber space. The APIs in the cyber space are to be invoked by the interactive components in the physical space, to interact with the digital subjects/objects/resources/services/activities in the cyber space. The data APIs are developed to store and retrieve the data to the blockchain, which locates in the values space.

(b) Digital subjects. There are three types of digital subjects, namely, digital twin subjects, digital associate subjects, and digital native subjects. For any specified subjects, for example, individuals or companies, every type of the digital subjects are developed with a generic subject meta-model for a Cyber-Farm, following the subject specifications, which are provided in the values space. The different roles of subjects apply the same meta-model, whether it is a technician or peasant, retired or employed, healthful or disable. The goal is to realize the values of non-discrimination subject in the Cyber-Farm.

(c) Digital objects. There are two types of digital objects, namely, digital twin objects, and digital native objects. For any specified objects, for example, plants or fishes, every type of the objects are developed with a generic object meta-model for a Cyber-Farm, following the object specifications, which are provided in the values space.

(d) Digital resources. There are two types of digital resources, namely, digital twin resources, and digital native resources. For any specified resources, for example, farmlands or houses, every type of the resources are developed with a generic resource meta-model for a Cyber-Farm, following the resources specifications, which are provided in the values space.

(e) Digital business services. There are two types of digital business services, namely, digital twin business services, and digital native business services. Among the digital business services are those for agricultural innovation, production, circulation, and consumption, just for examples. For any specified business services, for example, bank services or logistics services, every type of the business services are developed with a generic service meta-model for a Cyber-Farm, following the services specifications, which are provided in the values space.

(f) Digital activities. There are two types of digital activities, namely, digital twin activities, and digital native activities. Among the digital activities are social activities, recreation activities, cultural/games activities, business activities, and investment activities, just for examples. For any specified activities, for example, gaming, crowd-funding, or crop production, every type of the activities are developed with a generic activity meta-model for a Cyber-Farm, following the activities specifications, which are provided in the values space.

(3) Components in the values space

The data APIs are developed to store and retrieve the data to the blockchain, which locates in the values space.

(a) Trusted data infrastructure. A Cyber-Farm blockchain and a data repository provide a public trusted data infrastructure. All the data of the trigram space are stored in the data repository, including the data of subjects/objects/resources/services/activities, and the governance services. The copies of identified critical data, take the transaction data for example, are uploaded in the blockchain for possible tracing or testifying. Smart contracts are developed to support governance services of the Cyber-Farm to fulfill the agreed transactions.

(b) Governance specifications. The specifications are carriers of the rules, standards, and policies of all the elements of a Cyber-Farm. They are stored in the blockchain, and all the elements are developed to follow them. They are the "bible" of the Cyber-Farm, and they reflect and realize its values.

There are two types of governance specifications, namely, basic values and principles, and operation specifications. The first basic principle of a Cyber-Farm is to meet the overall gains of physical human. The second is to follow all the applied laws to be sustainable. The third is to govern the Cyber-Farm based on the values rules to make a fair, trusted, autonomic, efficient, and green community of interests.

Among the operation specifications are those for subjects/objects/resources/services/activities/security/environment, supporting services, public services, and administration services.

(c) Governance services. There are three types of governance services, namely, supporting services, public services, and administration services. Among the supporting services are crowd computing service, dispatching service, and evolving services to provide value-oriented collaboration schemes. Among the public services are data assets service and digital money service. The administration services are to manage all the elements of the Cyber-Farm, which are comparable to the government services in the physical space.

Both the data assets service and the digital money service are popular in the emerging metaverse applications. The data assets service is to discover the values of collection, recreation, or investment based on farming processes or products. The digital money service is to make a price index service other than issuing a cryptocurrency. A symbolic token is developed to circulate in the Cyber-Farm, as like as those in supermarkets.

4.3 Implementation and verification

(1) Implementation method

There are two options for Cyber-Farm development. One is to develop from the scratch on the implementation framework, while another is by integrating of the open sources following the proposed Cyber-Farm principles and objectives. The governance system of the values space in the Cyber-Farm is too complex to design, developed, and testified. Therefore, the author has developed a demo prototype through integrating several open sources of applications.

(2) Demonstration by a prototype

A prototype of Cyber-Farm has been developed by integration. The objective is to testify the proposed principles, concepts, and implementation framework. As illustrated in Fig. 14, the basic service by the prototype is "plant claim". Among the applications to be integrated are a blockchain platform for tracing and creditworthiness by Li et al.[29], a farm-like game with open

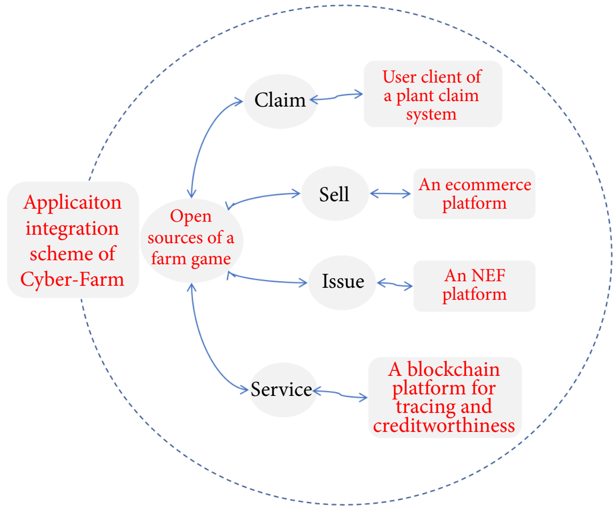

Fig. 14 An application integration scheme of Cyber-Farm prototype.

development environment, a Non-Fungible Token (NFT) platform with open APIs, and an ecommerce platform with open APIs.

As illustrated in Fig. 15, the farm-like game provides a cyber space and basic elements. With it as a development environment and a start point, the author has completed a number of integration and customization tasks. Firstly, a render model of farm plants, animals, and environments has been implemented and testified. And a number of goats, tree, and cloud have been developed to be changeable at appearance and growth status. Secondly, a graphic user interface has been developed and allow users to issue NFTs from the game (the cyber space of the Cyber-Farm). Thirdly, a graphic user interface to the ecommerce platform has been developed. Users somehow are allowed to sell agricultural products from the game. Fourthly, an interface is being developed to interact the blockchain platform for tracing and creditworthiness, which will allow users to check the plants information, or publish the plants in the blockchain. Finally, a claim interface can be developed easily to provide a user client of a plant claim service.

Basically, the prototype has been integrated and developed with very few and superficial functions and services. Beside the blockchain infrastructure, the most critical concepts such as the values-driven specifications, crowd-dispatching, and governance services have not been touched.

Despite the imperfection and disorganization, a number of concepts have been further recognized in sensual ways. Among them are, (a) the distributed physical subjects/objects/resources can be organized as a single unit in the cyber space, (b) both the healthful and disabled people can work for the physical farm remotely through operations in the cyber space, (c) it looks sound to keep the physical plants and goats to be consistent with their digital counterparts, and (d) the interfaces to the platforms of blockchain, ecommerce, and NFT, are easy to develop. It means the integration is feasible at interface level.

However, the further processes are too difficult to integrate with the platforms of ecommerce, blockchain, and NFTs. A major reason is that the Cyber-Farm are involved with many new rules and inconsistent processes, which need open process APIs of the integrated applications to implement and even work on the processes of the applications. Without predefined partner agreements with the application owner, only a few of proposed concepts and elements can be demonstrated separately and

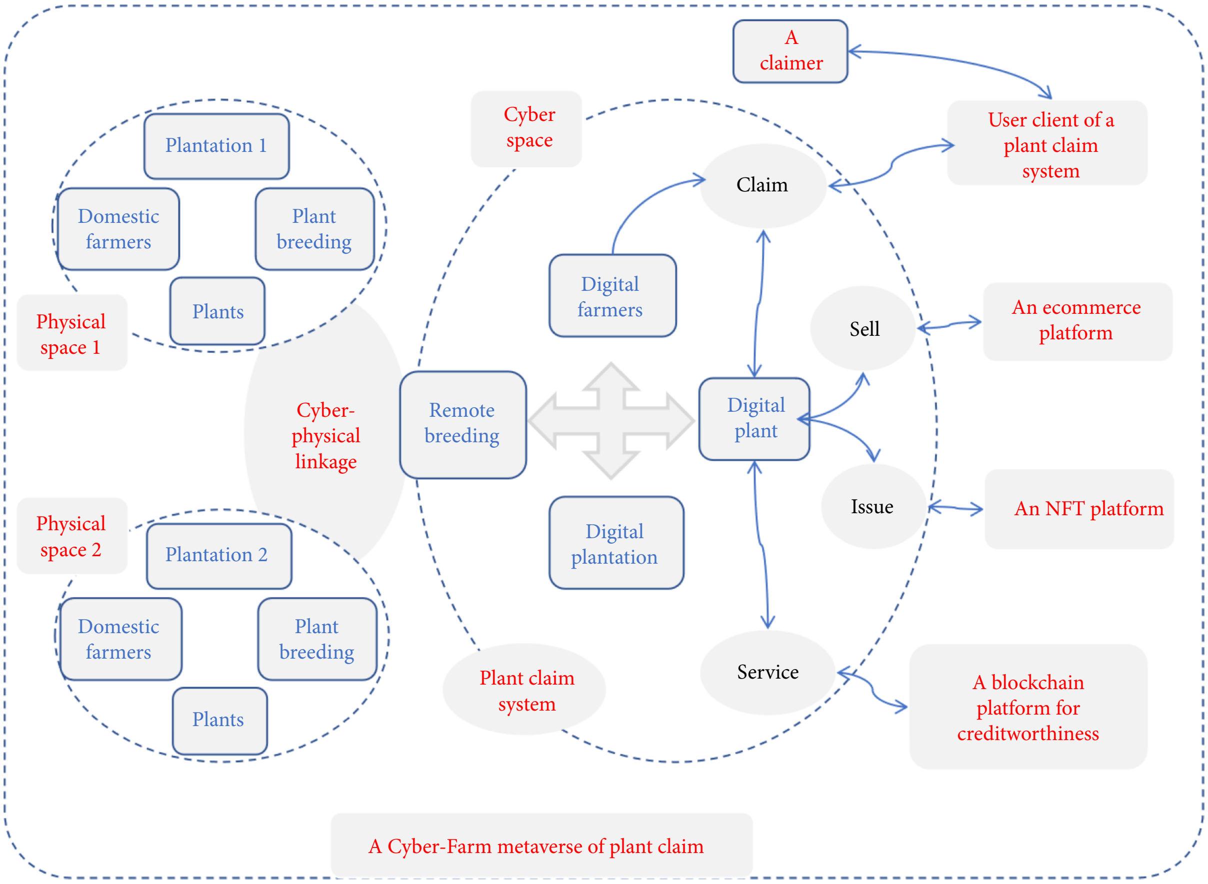

Fig. 15 A plant claim system to demonstrate the Cyber-Farm metaverse.

superficial.

5 Conclusion

In this article, it is found that the participants in the metaverse-related agricultural applications are designed as users rather than residents. There is another critical setback for the metaverse to be a fusion cyber-physical space, as the cyber space is subject to different values principles from the physical space. Based on the observation, a Cyber-Farm of trigram metaverse is proposed to be developed a values-driven and whole-profits-oriented crowd-dispatching. The Cyber-Farm is constructed on a unified trigram space through the fusion of cyber, physical, and values spaces. Based on a trusted blockchain infrastructure, the values space is a parallel and superstructure to the cyber and physical spaces. Further, the values space enables both the cyber space and physical space to follow the same values principles, and operate in a fair, efficient, and equal rules through a values-driven governance system.

Some basic discussions at the production means, production relations, and superstructure of the trigram metaverse have been presented. Both the resources and services are among the basic Cyber-Farm production means. The basic production relations of the Cyber-Farm of trigram metaverse are proposed to be “on-demand organizing, crowd-collaborating, and values-driven contracting”. Its superstructure is “values-based autonomic governance”. A number of essential issues, from which farmers, farming, and farms have suffered for centuries, have been identified across agricultural life-cycle. In a Cyber-Farm, the participants are its subjects rather than its users. All the agricultural elements are coming into being and evolving in the interlinked and unified trigram space. Based on the Cyber-Farm paradigm, all the connotations and scopes of farm, farmer, and farming have been redefined. The intentions, scenarios, principles, and elements of the Cyber-Farm have been restructured. Farmers are equal and with no any discrimination at identity and disability, farms are smart and green, and farming activities are crowd intelligent and collaborative. Theoretically, a potential grand vision is to bring about farm-featured Utopias parallel to human communities.

What make differences of this work is to identify and provide solutions to the critical issues of metaverse development, namely, a methodology of constructing a metaverse and fusion space with heterogeneous principles. Though the proposed principles, techniques, and implementation framework are basically initiative, a new arena could be set up for digital farm applications/metaverse. Further, a Cyber-Farm prototype and modelling methods to simulate natural environments, dynamic skies, vegetation, and water have been developed to demonstrate a number of its features. It is found from the prototype development that it is not feasible to implement a Cyber-Farm through application integration as the farm involved with so many of new processes and rules, which may not be consistent with the applications to be integrated. Despite of the disorganized attempts, a systematic prototype is too complex and expensive to be constructed for the proposed values-driven Cyber-Farm of trigram metaverse.

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The author would appreciate Prof. Yueting Chai and Professor Hongfeng Chai for their constructive instructions. Also, Mr. Shuo

Wang developed a prototype to integrate a game, an NFT platform, and an ecommerce platform to simulate business activities in a cyberspace. Ms. Shuxiao Geng studied and developed several modelling methods to simulate natural environments, dynamic skies, vegetation, and water to align physical space entities with virtual reality space entities. Both of their developments are helpful to understand the basic scenario and concepts of integrating physical and cyber farms.

Dates

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