NUNET

A Global Economy of Decentralized Computing

Whitepaper

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Summary

NuNet is a computing framework that provides globally distributed and optimized computing power and storage for decentralized networks, by connecting the owners of data and computing resources with computational processes in demand of these resources. Furthermore, NuNet provides a layer of intelligent interoperability between computational processes and physical computing infrastructures. It is an ecosystem which intelligently harnesses latent computing resources of the community into the global network of computations. NuNet infrastructure enables to optimally position AI processes, interfaces and data within the global network and establish machine-to-machine payment and data streaming channels -- thus minimizing costs of global computing and enabling novel business processes for the Data Economy and Internet of Things.

NuNet platform is designed to be an extremely flexible network, encompassing mobile consumer devices, edge computing and IoT devices alongside with PCs, servers and data centers, allowing seamless interoperability among its components and intelligent automation of workflow design. NuNet leverages Web3 technologies, serverless container execution, service mesh orchestration, crypto-economy and more, toward creation of the decentralized "world computer".

NuNet is a spinoff of SingularityNET Global AI Marketplace, operating since 2017. NuNet has been incubated via SingularityNET X-Lab Accelerator programme since early 2018. The technology development and early use cases of the NuNet platform will be geared towards (but not limited to) supporting the computational infrastructure of decentralized AI agents of SingularityNET.

Global volumes of computing capacities, data and computer code are growing exponentially on a continuous basis. However, due to the historical circumstances surrounding development of global computing infrastructures, computing, data and code are fragmented into silos with limited access available only for richest economic and social actors. The enormous economic and social value locked between the boundaries of those silos and the potential of decentralized technologies for unlocking them is being increasingly clearly recognized and addressed[1,2]. Using currently available computing resources for training state-of-the-art machine learning models is prohibitively expensive and can cost millions of dollars for a single training cycle. Therefore, the development and application of cutting edge AI and ML technology is not affordable for most researchers, individuals and SMEs.

NuNet aims at creating a framework for providing an interoperability and transactional layer connecting latent computing resources of privately and commercially owned devices, open

[1] Trent McConaghy. *The Web3 Data Economy*, OceanProtocol Blog, November 22
[2] FreedomLab. *Breaking down data & AI silos*, freedomlab.org, June 24, 2019.

source and proprietary code, data sources and storage into a single dynamically evolving Global Economy of Decentralized Computing. Through increased accessibility -- of resources to process owners, and of processes to resource owners, data to processes and storage to data -- NuNet will result in radically new capabilities of value creation and lower operating costs for the computational processes involved. In the fully functional NuNet framework:

- computing resource owners (of home or office PCs and laptops, IoT and mobile devices, etc.) will express and publish their specialized capabilities and offer them to processes that need them across diverse ecosystems;
- storage resource owners will express and publish their storage resource capabilities and offer them for data owners for free or in exchange for tokens depending on their individual preferences;
- computational process owners will express and publish their specialized computational and data requirements and bid for resources and know-how, as well as offer and/or spot-sell their own functionalities and capacities across the ecosystem;
- data owners will publish descriptions, access restrictions and privacy considerations of their data, allowing processes to utilize existing data and contribute to its refinement and growth;
- each participant (e.g. individual users or owners of resources) will be able to express their preferences of how the network should guide the usage of their resources and/or charge convertible cryptographic tokens for the usage of each respective resource;
- each participant (e.g. social and business enterprises) will be able to bid for free or paid usage of resources offered through the framework and to pay using native NuNet tokens.

NuNet will provide self-regulation of the interactions of three types of participants in the network: **providers** of data, compute & AI services, **consumers** of the data & compute (using AI, code and algorithms) and **network operations agents**. The latter will orchestrate creation, execution and verification of computational workflows connecting providers with consumers into ad-hoc service meshes, where each service is potentially provided by a different entity and compensated according to its preferences. Network operations agents will ensure correct and timely provisioning of services from decentralized peer-to-peer network, confirmation of executed processes, and correct compensation for services for each service provider according to its preferences and the work done.

In most simple cases, processes operating on NuNet may be simple, standalone computing processes intended to be executed in isolation, in which case NuNet would simply provide adequate computing power and data sources for these simple processes to be completed considering cost constraints. However, the processes themselves may also be participants in various different decentralized networks, having their own tokenomics and ecosystems. In the latter case, NuNet realizes what is called a ***meta marketplace economy*** (MME) -- a modality of operation that will become increasingly valuable over the next few years, as the "network of networks" aspect of the emerging decentralized economy transitions from

concept to reality with the increased adoption and interoperability of decentralized computing networks (e.g. SingularityNET, DAIA members and others).

In most advanced case, ultimately targeted by NuNet as a basis of the global economy of decentralized computing processes, network operation agents will relate data & compute providers from different decentralized (and possibly commercial) computing frameworks with AI, code and algorithms of diverse entities into service-mesh type ad-hoc workflows. NuNet governance and tokenomic framework will ensure that a contract for computational work demanded from a workflow by consumer is delivered and each component of the workflow is compensated according to work done, agreed prices and using cryptographic tokens of involved frameworks and computational engines.

The meta marketplace economy of NuNet will be supported by the network operations agents using, among other mechanisms:

1. a native token, interoperating and compliant with the tokens and other value exchange mechanisms already implemented within the ecosystems supported by the NuNet framework; and
2. a governance paradigm geared towards establishing rich collaborations among human as well as AI agents over an open-ended, heterogeneous globally connected infrastructure.

NuNet is designed to serve both commercial and social-impact ends, in a synergetic way. It will serve as a commercial ecosystem supporting a growing number of businesses in need of highly customizable and dynamically distributed computing as well as purpose-optimized workflow design for low cost distributed computing behind their decentralized applications. It will also support the global benefit of society by introducing initiatives and projects where NuNet participants can donate resources and know-how towards solving critical global problems.

Global computing infrastructure

Current state: data and computing silos

The decentralized NuNet network is designed to operate effectively within a technological ecosystem currently working according to quite different organizational principles. The current global computing ecosystem and market is largely oligopolistic and vertically integrated, and is mainly dominated by large ‘cloud’ infrastructure providers, such as Amazon WS, Google Compute Engine, MS Azure, and software-as-a-service providers, such as IBM, Oracle, Salesforce, SAP, and others. Most of these providers offer powerful computing platforms within which they provide tightly integrated ecosystems of paid data storage, data processing, and machine learning and AI algorithms. Consumers of these cloud computing infrastructures often use more than one provider, integrating these infrastructures with their own in-house infrastructures, resulting in multi-cloud and

hybrid-cloud infrastructures,[3] thus pushing providers to develop appropriate solutions towards such ends.[4] However, cloud computing providers that offer tools enabling design and efficient operation of computing workflows, must use their own proprietary solutions and components, which often duplicate those of their competitors[5].

The size of the Infrastructure as a Service (IaaS) market worldwide accounts for about 22% of the whole public cloud market and is the fastest growing component of it, amounting to 36 billion USD revenues in 2018[6]. It is estimated to grow 23% yearly and reach 59 billion USD by 2023[7].

Cloud computing ecosystems are therefore to a large extent isolated. For example, processes and computing pipelines implemented on Google Compute Engine cannot at any deeper level integrate with computing pipelines implemented on Amazon WS. Historically, this was justifiable by the fact that the physical concentration of computational resources provided better speed and efficiency, mostly due to fast communication within data centers. This state of affairs, however, is becoming obsolete and hinders the computing market potential and further development. Most importantly, huge amounts of unused computing power and data are scattered hidden in private computers, mobile phones, wearables and other private devices. The data produced by private devices, while legally owned by the device owners, is in most cases controlled and accessible by vendors and cloud providers. The raw data accumulated in IoT arrays is locked and controlled by device manufacturers and their proprietary cloud infrastructures. Again this is dubiously justified by the requirements of security and privacy which are currently addressed by creating sealed and centrally managed data silos within each vendor's boundaries.

This creates a situation where the already radically decentralized physical infrastructures are managed in a centralized fashion which, as recent examples show, becomes sub-optimal even with respect to security and privacy considerations that justified the closed centralized infrastructures in the first place. It becomes sensible if not critical that future computational architectures could and should be able to take advantage of such latent or siloed resources of both computing power and data.

"Cloud wars" notwithstanding, the global computing landscape is getting disrupted by new technologies of the emerging data economy. *Edge* and *fog* computing are beginning to

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[3] ZDNet, January 2019, Cloud customers pairing AWS and Microsoft Azure, according to Kentik (https://www.zdnet.com/article/cloud-customers-pairing-aws-microsoft-azure-more-according-to-kentik/)

[4] ZDNet, April 9, 2019, Google's app management platform aims to connect clouds -- even AWS, Microsoft Azure; TechTarget, May 30, 2019, Azure Cost Management adds AWS, reflects multi-cloud strategies.

[5] AWS Data Pipelines (https://aws.amazon.com/datapipeline/), Google Cloud Dataflow (https://cloud.google.com/dataflow/), Azure Logic Apps (https://docs.microsoft.com/en-us/azure/logic-apps/logic-apps-overview), Alibaba Machine Learning Platform for AI (https://www.alibabacloud.com/product/machine-learning), etc.

[6] IDC Worldwide Semiannual Public Cloud Services Tracker, 2H18 https://www.idc.com/getdoc.jsp?containerId=prUS45411519

[7] GLOBE NEWSWIRE, July 2019 https://www.globenewswire.com/news-release/2019/07/30/1893891/0/en/Infrastructure-as-a-Service-Iaas-Market-Is-Estimated-To-Reach-Usd-59-Billion-By-2023-Cloud-Technology-to-Ensure-Better-Growth-for-Infrastructure-as-a-Service-Market.html

distribute computing power across broad geographical networks of devices, and is being enabled by a variety of new technologies including ultra-fast broadband, wireless and mobile internet connections, a steadily increasing mass of mobile devices with significant storage and processing capacity, and advanced autonomous robots. Distributed computing technologies allow for stream computing, microservice architectures and Internet of Things ecosystems that can logically manage and execute workflows across different machines and geographical locations. Advances in artificial intelligence and machine learning technologies have allowed algorithms to perform efficient data transformations autonomously, or with minimal human intervention. Lastly, distributed ledger, and related technologies featuring cryptographically secure identification, automated trustless interactions and smart contracting as well as reputation management and more, enable incredibly fast and efficient micropayment exchanges among individual processes and microservices, again with little to no human intervention.

Given these recent developments, still rapidly unfolding, all the major building blocks needed for a globally decentralized computing and data economy are already in place today. And yet, the computing platforms of centralized cloud providers are still largely constrained by closed networks, proprietary payment systems and hard-coded provisioning operations.

These seemingly highly technical points have an importance for humanity and its future that should not be underestimated. The computational universe is becoming an increasingly important part of our life in the physical universe, and has already surpassed the imagination of science-fiction writers of only a few decades ago. But despite these incredible advances, this is barely the beginning of the computational revolution. If we think in Kurzweilian terms regarding a Technological Singularity potentially occurring toward the middle of this century, we can say that the majority of the specific technologies that will underlie this Singularity have yet to be created and implemented. The principles according to which we build, operate, use and share computational resources in our physical and computational universes, will greatly influence our ability to tap into human creativity and shape the future of our world, in these critical next few decades as AI systems and other computational networks come to more and more greatly exceed human capabilities in various regards.

NuNet: A flexible, decentralized computational universe

Technological advances of the last decade, in computer science and allied areas, enable numerous possibilities beyond the centralized and oligopolistic technology infrastructures that have become economically dominant. They afford a great variety of options for implementing radical innovations in the management of global computing resources for the benefit of all. What is needed is an economic and computational context in which experimentation with, exploration and interconnection of multiple innovative potentials occurs freely and rapidly and is driven by a broad variety of human and AI actors.

NuNet provides such a context, via creating a global scalable decentralized computing framework fostering a multi-marketplace community of pragmatic pioneers. It achieves this via:

1. Breaking barriers that prevent interoperation of fundamental computational components owned by the general public and different economic players;
2. Enabling interoperation of human and machine intelligence for designing, implementing and executing components, and their combinations, in the global computational framework;
3. Decoupling computational processes from physical computing infrastructure and location by enabling fluidity and mobility of the computational workflows across multi/hybrid- clouds and diverse proprietary resources.
4. Developing ontology, semantics and APIs for providing computational reflection, location and context awareness information to computational processes, enabling intelligent workflow creation, learning and meta-learning with limited human intervention;
5. Developing the framework for fair and secure exchange of value of data created by each computational process, mobile device, resource and its owner participating in the ecosystem, where the value can be negotiated in local exchanges without central authority or control.

NuNet's data exchange and computing framework will enable the integration of distributed computing technologies into a decentralized and scalable network, allowing for anybody to share, monetize and utilize the value of individually owned memory, computing capacities, algorithms, code and data, human creativity and machine intelligence.

There is a broad, deep aspiration here: ultimately, NuNet aims at supporting the elevation of intelligence and the overall efficiency of our computational universes into the next level. There is also a nitty gritty practical aspect: anyone can earn tokens and money (of various sorts) via simply installing a NuNet app on their phone; various sorts of compute processing needed by various businesses will be achievable at lower cost than using alternative methods; and some kinds of data/computing combinations that are now infeasible, or accessible only to tech giants, will become more broadly available (e.g. large-scale analytics of data collected via individual smartphones).

NuNet will enable computational processes (i.e. *agents*, to use a more concise term) to enact a variety of critical capabilities, leveraging the infrastructure providers and vendors that also play a key role in the network, in a manner orchestrated by the NuNet network operations agents. It will enable agents to:

1) exchange capability and action information between each other;
2) express the value of their capabilities and actions in chosen currency units or cryptographic tokens;
3) exchange this value between each other in any chosen form, giving rise to ad-hoc value and thereby creating networks of high complexity;
4) create additional value (local, global, economic, social...) by performing individual or collective actions in the network;
5) learn about actions, performance and capabilities of other agents or value creating networks;
6) encapsulate any simple or complex computational process, AI or ML engine and interact with humans for leveraging human intelligence for their actions;

NuNet platform will create social and economic value via:

- Enabling cheap computing power to be sourced for executing socially beneficial, community oriented applications and/or research purposes and enabling latent compute resource owners to earn additional income or donate their resources for beneficial usage.
- Providing an ability to organize global compute processes involving many computing steps, data sources and their novel combinations which are not available via traditional commercial cloud computing services.
- The fully functional NuNet framework will provide value to businesses by intelligently and automatically organizing computations without human intervention or with minimal intervention. Initially, consumers will be able to provide clearly defined business processes to be ingested and executed on the platform. Eventually however, they will be able to provide high level declarative descriptions of their needs, which would be 'compiled' to a network of computing processes, AI agents and data sources. Further, these 'compiled' workflows will be optimized based on actual distribution of data, computing power and their capabilities. Even further, the network will re-optimize computing processes automatically when new data sources, and more efficient or capable algorithms get introduced into the framework.

Breaking the barriers of data silos, concentrated hubs of computing power and centralized utilization of software and code, NuNet has the potential to play a key role in shifting the state of global computing from oligopolistic and monopolistic structures to open collaboration and resource sharing without compromising security and privacy, where network effects of disruptive technological developments are fairly shared by all constituents of the system -- rather than being available only to super rich companies.

System architecture

Overview

NuNet framework will allow for different computational processes, combining runtime implementations of open source or proprietary code, to be posted and executed on any device connected to the framework and offering its computational capacities. It will also allow for these computational processes to access various data sources advertised within the framework. The internal NuNet tokenomics will wrap the technical architecture into an economic framework, providing appropriately governed market incentives available for each participant in the network and beneficial for the self-organizational dynamics of the framework.

- *First*, at its very core, the architecture of Nunet will provide an open-ended collection of pluggable APIs, enabling independent and economically / socially incentivized participants (consumers, producers and network operations agents) to inject and/or

consume information into/from the decentralized data, management and control plane of the framework;

- *Second*, NuNet will provide a decentralized control plane for the network participants to autonomously construct and execute ad-hoc computational workflows combining independent computational and economic actors;
- *Third*, NuNet will provide tooling and development environment and tokenomic incentives for third parties to augment and/or completely redesign any network component or API.

The first and second aspects are instrumental to NuNet framework operation and will be initially developed by NuNet Foundation. However, the achievement of long term vision and ambition of NuNet, all three aspects will have to be continuously developed and support each other. The third aspect is instrumental for attracting community and business partners.

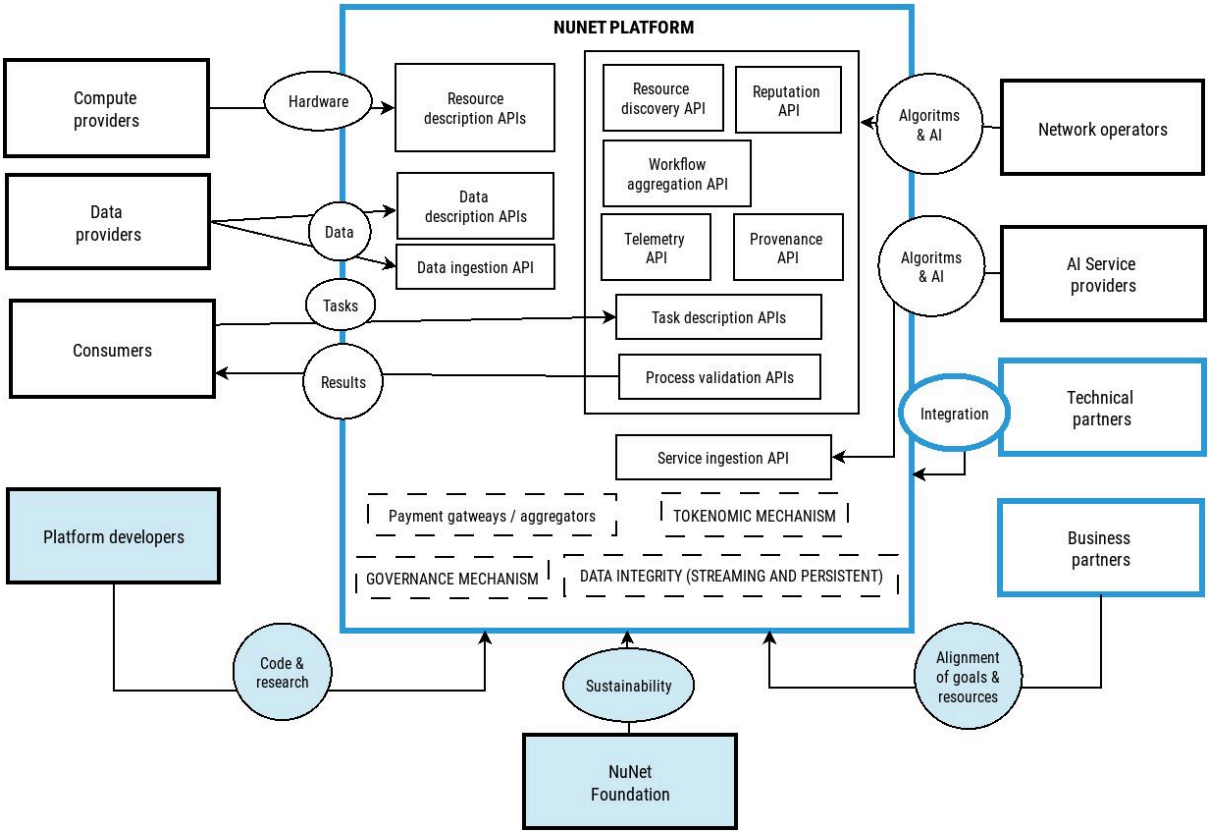

Figure 1: NuNet platform is a open-ended collection of pluggable open API, enabling providers, consumers and network operating agents to autonomously construct ad-hoc computational workflows from available components.

The collection of pluggable open APIs and the decentralized control plane will allow NuNet to operate as a decentralized service mesh -- or rather as an ecosystem of ad-hoc service mesh implementation of each computational workflow. It is decentralized in the sense that it does not have a single controller or orchestrator and each ad-hoc mesh network implementing a computational workflow and its runtime environment will be completely autonomous from each other. Furthermore, each ad-hoc mesh network is decentralized in

the sense that it is constituted from economically independent and computationally isolated components/ participants. Network operation agents are those components of the infrastructure that will provide independent construction, orchestration, execution, clearing and settlement of all computational and tokenomic transactions involved in ad-hoc service meshes. Network operations agents, however, will be economic actors on their own and therefore will be able to offer their underlying computational workflows within the same NuNet framework and infrastructure of open APIs. Therefore, NuNet will build the basis for a dynamic, infinitely extendable and evolving ecosystem of ad-hoc service meshes of ad-hoc service meshes -- a decentralized computational universe and a global economy of decentralized computing.

All computing processes, no matter how powerful or simple, are based on three fundamental aspects: *memory*, *communication* and *functional transformations* of data. Computational infrastructures at every scale are built by providing increasingly complex architectures for combinations of the components that realize these three aspects. None of them are free of charge: implementation of memory and communication require both physical resources and energy, and design of functional transformations require intelligence and time. In addition, all of these computing processes are certainly associated with specific types of legal ownership and economic value.

The architecture of NuNet is based on the principle that physically and logically decentralized networks should also be managed in a decentralized way, which, contrary to the established approaches, allows one to *increase* the security and privacy of network constituents, along with providing next level capabilities for optimized data and work flows. We are convinced that decentralization, openness and freedom of data and resource sharing do not need to be traded for individual security and privacy; but can actually complement and enforce each other if done right using available technologies. The philosophy of design is therefore based on the core principle of decentralized systems and distributed trust, where network is considered insecure and trustworthiness of messages and identities of workflow components questionable until this is proven at the level of each individual agent of the network. NuNet adapts and expands this principle for decentralized workflow organization, where each node of the network has a power to decide, negotiate economic or social benefits and commit resources and data to the computational workflow organized in a decentralized manner by other nodes in the network.

Technically, these principles will be realized via the following architectural components:

1. An open and organically evolving ***API of APIs*** for enabling interactions between components of the platform as provided by stakeholders:
    a. hardware (sourced from compute providers);
    b. data (sourced by data providers);
    c. tasks and results (consumers);
    d. and AI services (sourced from AI service providers and network operators).

2. Lightweight **NuNet adapters** running as portably as possible across the participating decentralized computing networks and infrastructures. NuNet agents will provide a low level API to be utilised by computational agents of enabling four main

functionalities: computational reflection, context awareness, mobility and value exchange. NuNet adapter will be installed on every component upon registration on the platform but will expose different APIs depending on the type of component (e.g. resource description API and service ingestion API on compute providers and AI service provider nodes, task description and validation APIs on consumer nodes and various APIs on network operator nodes, etc.);

3. ***Network operating agents***, which will provide capabilities and AI services for managing the NuNet network itself, including matching demands of consumers with offers of computational capabilities and available data by producers; constructing, calculating costs, time and orchestrating proper execution of computational workflows as ad-hoc service meshes -- composed from independent components. Technically, network operating agents will be special purpose AI algorithms and programs, executed on the NuNet infrastructure like other components and exposed to API of APIs via NuNet adapters. Network operating agents, however, will have special status in that they will be responsible for execution of each computational workflow, negotiate smart contracts and settle transactions.

4. ***NuNet tokenomics***, providing, on the one hand, the basis for value interchange between independent components of the network, single basis for cost calculations, transactions, and, on the other hand, the economic dynamics driving sustainable network development (see Tokenomics and Governance section of this document).

Computational and functional principles

Computational reflection

NuNet will provide means for computational actors to exercise certain levels of computational reflection in terms of: (1) resource allocation, (2) data representation, (3) execution introspection:

The *physical resource allocation* aspect of computational reflection will allow agents to have continuous interaction with their execution environments, and search and request for additional computational resources and infrastructures according to their own criteria. Additionally, agents will be able to download or update required libraries, i.e. evolve their own execution strategies, and this will allow for agents' free migration from one node (virtual machine, cloud vendor, private computer or a mobile phone) in a distributed computing environment to another;

Capability and data representation aspect will allow agents to semantically represent their own computational capabilities and input and output data. This information will be made available for other agents to query when negotiating pairwise contracts and workflow designs;

Execution introspection is the ability of each agent to monitor actual resource utilization by its algorithms, keep history of execution times and memory usage, and access its own state during execution, amongst other features. Agents may decide

to share part of this information with the network in order to prove their capabilities and quality of services;

Note that the abstraction of NuNet does not define in any manner how computation or actions of agents will be performed. Using means of computational reflection, computational agents will be able to design and apply workflow design and workflow execution functionalities pertaining to their individual choice and requirements. Furthermore, a human element can be seamlessly incorporated into the same model. For instance, an agent can represent a UI through which tasks that need human intervention can be performed and integrated into the workflow. A hybrid computer-human collaborative case can be imagined where NuNet workflows formulate a computational task, which is then performed by humans through crowdsourcing or freelancing marketplaces (Amazon MTurk, Udemy), or even code hosting platforms (GitHub, Bitbucket, etc.)[8]. The tokenomy of NuNet will support and facilitate decentralized marketplaces where human and machine jobs will be demanded, offered and contracted on a commercial or other basis. Computational reflection will enable owners of resources to advertise and price their capabilities and for resource users to estimate, track and manage computation costs in a dynamic and transparent way.

Context awareness

Context awareness, provided by NuNet agents, will amount to awareness of location and proximity to other NuNet agents in the network. Proximity in this sense means the cost of collaboration with these agents and includes a list of parameters which may be agent specific and therefore not centrally managed. Considering the wide variety of hardware devices, the network of NuNet agents will constitute a dynamic topology where physical location of resources may change over time, as well as resources can go offline and pop-up in other places. The topology of NuNet's network, however, will be defined not by geographic distribution of physical resources, but rather by the relative costs of transferring data between agents in a workflow in terms of time and price. Each NuNet agent installed in a particular device or resource will accumulate, keep and update this information upon request and provide it to computational agents via an open API. Note, that NuNet agent will be radically decentralized in the sense that no meta-agent will control or have information about the whole network. Therefore context awareness functionality will include methods of querying and learning local network topologies by individual NuNet agents, eventually supporting and enabling automatic or semi-automatic search and discovery of computational processes as required by clients or other processes in the ecosystem, independently of the network or physical location of processes.

Mobility

NuNet agents will support mobility of computational processes by enabling them to move between devices of the network and in this way enabling the dynamic optimization of computational workflows and business processes -- bringing data closer to processes or processes closer to data. All computational processes are containers, which can be spun

[8] Algorithmic governance of decentralized applications (DApps) was one of the original ideas behind the Ethereum world computer ecosystem.

and installed at the location of choice. Choices of moving containers across the network will be made by workflow organizers (i.e. network operations agents), while NuNet will provide necessary APIs providing context awareness and computational reflection information as well as support installation and destruction of containers as instructed.

Note that mobility of computational agents provides not only for the greater efficiency of computational workflows by enabling processing closer to data, but also completely new business models. For example, highly sensitive data can be processed at client's site by planting containers with proprietary AI / ML algorithms within the boundaries of the clients private cloud and ensuring that no data is leaked. Containers with algorithms may be cryptographically signed and secured and NuNet will ensure that the container is destroyed when the computing job is done, in this way securing privacy and intellectual property of both data and computing intelligence providers.

Value exchange

An essential part of NuNet is the tokenomic mechanism which will enable the network to connect computational resources, data and algorithms owned by different vendors into one network. NuNet adapters will therefore enable to exercise payments to resource owners directly from the computational agents of distributed computing frameworks or for individual users using NuNet. The goal of NuNet is to overlay the computational network with the payments network and provide interoperability and exchange adapters for tokens and payment methods used by owners of computing resources, decentralized computing platforms and marketplaces.

The value exchange between independent network components will be based on an established smart contract platform and decentralized micro-transactions. Initial value exchange infrastructure will be implemented on Ethereum blockchain, but NuNet architecture will allow to work with different distributed ledger technologies as long as they provide smart contract and decentralized micro-transaction capabilities as required by the platform. Ultimately, when the platform will be at an advanced development stage, it may allow a network operation agent to choose a smart contract and transaction platform from several options and to extend the framework with new technologies appearing in the space.

Supported functionalities

NuNet's APIs will support the functionalities of decentralized computing platforms and marketplaces, initially of SingularityNET and members of the Decentralized AI Alliance (DAIA). These functionalities include, but are not limited to:

Mobile computational processes

A computational agent encloses a computational process that turns input data into output data, without any restriction whatsoever on the nature of the process or the amount of computational resources that it needs. Agents isolate the process' computational logic from the physical implementation, resources and location. A computational process encapsulated into an agent can be any combination of memory and processing, which can range from

complex AI and machine learning processes to simple queries for retrieving data from a database or a streaming datasource. The abstraction layer that isolates computational logic from physical implementation enables agents to be agnostic to the physical infrastructure and location, which can be dynamically changed as per demands of specific workflow.

Flexible workflow design

Agents are building blocks that can be combined to form arbitrarily complex domain specific computing workflows that can perform a variety of useful computations in the network. The same agent can participate in many workflows, and connect with other agents to form clusters. Agent mobility enables such workflows to operate across boundaries of cloud vendors, mobile devices, private clouds and more, while respecting and ensuring ownership, economic value of resources, and data security/privacy are maintained by the respective parties. NuNet implements a tokenomic mechanism to enable and facilitate the design of frictionless cross-vendor workflow execution.

In terms of *workflow design*, agents, using NuNet's functionality, will be able to search for other agents in the network, which could provide building blocks for their original task, calculate the costs of such workflows, and estimate time requirements of execution. This would allow for agents to make optimal decisions with or without help from humans, and enable agents to express larger computational tasks that would be difficult for one agent to achieve.

The *workflow execution* aspect of computational reflection will enable agents to time, schedule and manage the actual execution of their workflow, data transfers between agents, error propagation, crash recovery, necessary caching, etc[9].

Data and value production & exchange

Inputs and outputs of computational processes are data, whereis data has its own inherent value. The value of data, however, is not absolute, but instead relative to what other participants of the ecosystem (i.e. computational processes) can do with it and how they value it with respect to ecosystem's dynamics. Data's value, broadly speaking, is context dependent and is subject to negotiations between providers and requesters. Entities can value static data (e.g. stored in a database) or dynamic data (e.g. real-time streaming) that is time sensitive, private or public, and useful in either broad or very specific contexts. Also, it is important to keep in mind that data has associated costs -- of production, storage, analysis and transformation. As these costs become more transparent, specific solutions can be designed for various stages of the data creation/analysis life-cycle and these open and collaborative efforts could likely result in the reduction of transactional data costs and the ability to deliver improved insights. Transparent, secure and efficient matching of all data forms to the immediate requirements of societal, business, government and individual

[9] E.g. using large scale data processing and stream processing engines, such as Apache Flink, Apex or others.

processes will tap into the enormous economic potential of the data economy[10], which for the time being is still waiting to be unlocked.

NuNet provides tools for the economic exchange and sharing of data (which may be, but is not necessarily free). Note, that in a computational workflow data can be very specific and time sensitive, i.e. produced purposefully for the next process, and by converting input data to output data, agents *produce value* which they can then exchange with other agents on the basis of a tokenomic mechanism. Since the value of data is different for different agents, NuNet enables a decentralized value exchange mechanism, based on, but not limited to, pairwise negotiations and contracts between computational agents. NuNet's tokenomic mechanism will also enable solutions for tamper proof traceability of resource consumption, data provenance and vendor-consumer relations. It will provide the basis for enabling companies and customers to accurately trace and manage their spending and decentralized partnerships.

Logical scalability

Computational reflection of agents, especially in their workflow design and execution aspects, will allow entities to create workflows (i.e. logical structures) in the network in a decentralized manner (see picture below). In a decentralized network, meta-agents can act as intermediaries that transform input data into output data through the curation of other agents' computational services, which ultimately can be expressed as a logical structure consisting of a variety of agents existing in a connected network workflow. So while such a meta-agent uses the same abstraction as other agents in the network, internally it holds only the computational reflection (or representation) of a workflow: the identities of agents in workflow, their inputs and outputs, their cost, location and data offered, as well as scheduling information needed for designing and executing a workflow[11].

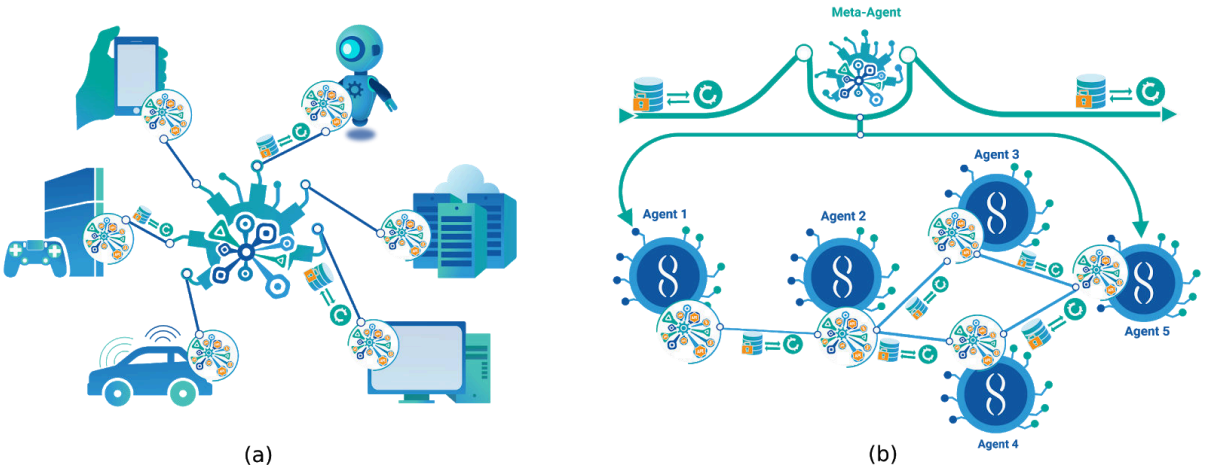

Figure 2: (a) Computational workflows will involve computing power and data of various devices enabled by NuNet adapters installed on each device and network operating agents orchestrating them; (b) Meta-agents will be able to create complex

[10] https://en.wikipedia.org/wiki/Data_economy
[11] E.g. using Apache Beam -- a unified programming model for defining data processing pipelines.

computational reflections consisting of a hierarchy of sub-meta agents, all the way down to base agent services hosted on supported decentralized computing platforms, such as SingulairtyNET.

Once the computational reflection is fully mapped out by a meta-agent, the workflow can be executed entirely at their discretion, provided that the initial data and the amount of tokens covering the costs of all computational agents within the workflow are covered. Note that as meta-agents are able to design workflows involving other computational agents, similarly meta-agents themselves can be incorporated into higher order workflows giving rise to the logical scalability property of the network. Meta-agents will be able to create complex computational reflections consisting of a hierarchy of sub-meta agents, all the way down to base agent services, that are constantly and dynamically changing their costs, workflows and services offered. Furthermore, these workflows can be designed by a human operator, automatic procedure or an AI agent using the same level of abstraction. These functionalities will give rise to what call a *decentralized network of dynamic service meshes*.

Verification and validation

An obvious requirement and one of the most important aspects of the framework's functionality is the ability to verify and validate correctness of computational processes performed in a network and establish a way to validate good users / components, reward good actors and punish bad actors.

Ability to verify and validate each general computational process in a decentralized network can only be performed in a decentralized way, which means that NuNet as a whole will not attempt to provide guarantees of correctness of each process and computational workflow performed in the network. Instead, the framework will provide APIs, tools, network-wide telemetry information and reputation system(s) that will enable each constituent of the network (network operations agent) to evaluate the validity and correctness of concrete results of computational processes in question. Through network-wide telemetry information available to all constituents of the network, NuNet will facilitate self-learning and healing capabilities of the framework effectively minimising impact of bad actors to the overall network performance as well as results of individual computational processes.

Main aspects which will ensure the reliability of the NuNet network and validity of its individual computational processes are:

(1) the tokenomic mechanism supported by implicit and explicit reputation systems, on top of technical means of verification and validation, will provide immediate and clear economic incentives for the good (i.e. beneficial for all) behavior of network constituents;

(2) the variant of the non-repudiation / proof of receipt mechanism[12], where new tokens will be minted and distributed to platform users upon successful completion of a transaction and based on actual computing power used by this transaction -- a crucial part of NuNet tokenomics.

[12] Coffey, T., & Saidha, P. (1996). Non-repudiation with mandatory proof of receipt. ACM SIGCOMM Computer Communication Review, 26(1), 6–17. doi:10.1145/232335.232338

(3) NuNet will also make the best use of formal third party verification tools, such as developed by SingularityNET, TrueBit, zkSNARKs or other open source protocols or even businesses, as well as encourage using secure hardware enclaves. However, formal verification methods are an active research field and not available for verifying computations *in general* -- only specific cases. Therefore, NuNet will mostly rely on tokenomic and reputation based mechanisms, while integrating formal work verification methods for specific use cases where it is appropriate. In the future, NuNet will aim to provide an API for integrating third party formal verification tools for general usage.

An ecosystem of adaptive decentralized computations

NuNet will support the principle of radical decentralization of the computing platforms and marketplaces in the sense that every agent will be able to become a meta-agent if it decides to do so and has computational, cognitive, and financial resources or the support of human operators to execute such roles. Given a large enough number of agents operating in the network, their ability to form workflows on their own will lead to pluripotency and degeneracy (i.e. many-to-many relations of structures and functions), competition, cooperation and capacity of the network to self-organize into progressively more complex cognitive structures.

In the decomposition of NuNet participants into computational resource providers, computational resource users and network operations agents, meta-agents may fall into any of the categories; or a single meta-agent might span 2 or 3 of the categories.

Learning and meta-learning

Computational agents will be able to express any computational algorithm, AI or a machine learning engine, and will also be able to access information about their own and other agents' capabilities through NuNet, as well as the history and activity in the network. Therefore, agents will be able to learn from experience about the credibility, efficiency and security of other agents, and also about other dimensions and activities happening in the network. Different meta-agents may start to specialize in analyzing other agent's reputations and rating their performance, and then providing this information to other agents in exchange for tokens or information. These intricate interactions ultimately will give rise to a decentralized ecosystem of reputation systems within the network, that humans and machine agents will be able to examine and rely upon when designing computational workflows. Overall, these capabilities will allow individual agents to learn from their own, or network, experience and become better at performing their task and allow them to be adaptive to changing circumstances, new algorithms, cutting-edge AI engines and novel use cases.

Human-mediated cognitive development

Ecosystems of adaptive decentralized computations, whose individual agents are capable of learning and meta-learning in collaboration with each other, will give rise to the learning and adaptive capabilities of the decentralized marketplace of NuNet as a whole. Since some

agents will represent humans participating in the network, and in the beginning human agents may contribute the largest part of intelligence of the network, the framework as a whole will be able to learn from human actions and intelligence and progressively undergo cognitive development. Governance mechanisms of NuNet will guide this evolutionary development for the benefit of all.

Business and operational model

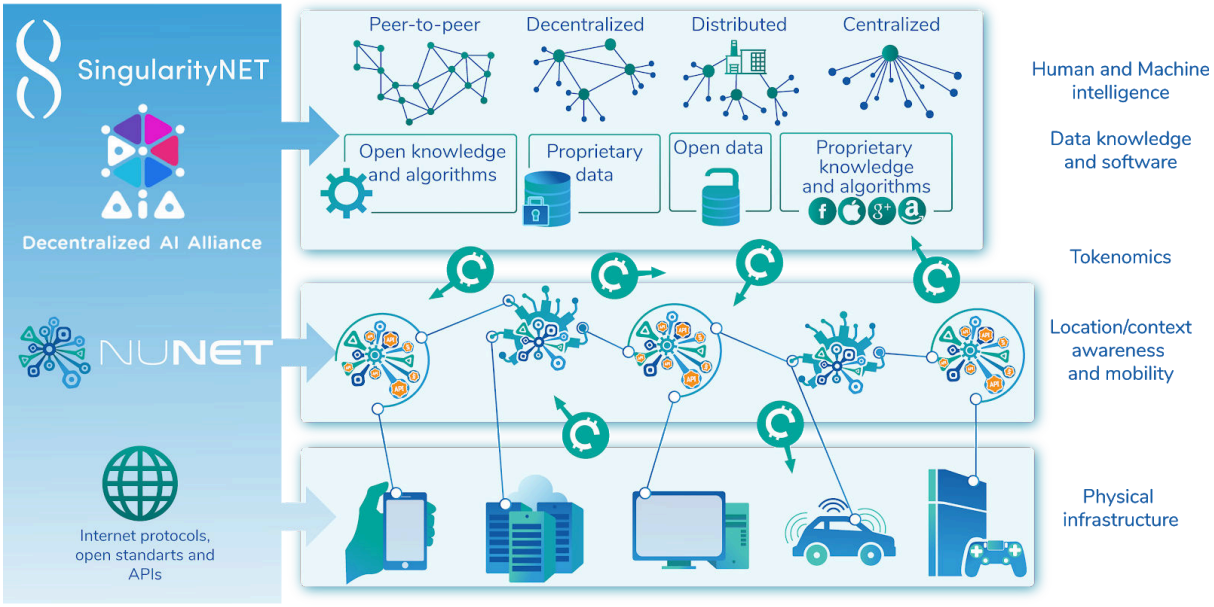

Figure 3: Conceptual business model of NuNet platform

Multi-sided platform

From the business model perspective, NuNet is a multi-sided platform[13] enabling direct interactions between different stakeholder groups (see Figure 1 and Figure 3). In order for the platform to operate so that it could advance NuNet's vision, it will have to satisfy the interests, demands and capabilities of each stakeholder. NuNet platform will provide value added for each stakeholder group so that they would be incentivized (directly or indirectly) to use NuNet platform versus other offerings in the market for advancing common as well as individual goals. Main NuNet stakeholders/constituents are:

[13] A multi-sided platform is a business model, where value is created by enabling direct interactions between two or more distinct types of affiliated customers / constituents / stakeholders. Some examples of multi-sided platforms are AirBNB, eBay, Uber. More traditional two-sided business model is a platform which has two user groups that supply each other and provide network benefits, such as American Express, Facebook, LinkedIn.

Compute providers

Compute providers are individuals and organizations which register their computing capacities to NuNet platform and enable them to be discovered and used by other platform users.

Capabilities: Latent computing resources of owned devices;
Demands: Optimize usage of existing computing resources. The optimization criteria can differ for each provider – it could be e.g. earning additional income for underutilized computing capacities, donating existing capacities to chosen socially beneficent projects, enabling new internal or external business processes, etc.;
NuNet offer: Allow compute providers to offer a chosen amount of latent computing power to other users via NuNet platform subject to custom criteria, using resource description and discovery APIs;
NuNet requirements: Providers will have to describe their devices and usage preferences; NuNet will install a NuNet adaptor on each sourced device which will enable the telemetry API;
Potential users: Individuals and organizations having latent underutilized computing power and wishing to donate it for socially beneficial causes or for crypto-income as well as in need for innovative business processes;

Data providers

Data providers are individuals and organizations who register their data sources to NuNet platform and enable them to be discovered and used by other platform users[14].

Capabilities: Ownership or control of data that could be useful if shared; Note, that data could be static (a database on a permanent server), dynamic (a constantly changing data in a distributed network) or streaming (sensor readings from IoT devices or mobile phones).
Demands: Optimize the usage of data (e.g. sell data on an ultra-granular level, share data with partners, industry or larger community);
NuNet offer: Allow data providers to offer their data to other NuNet platform users subject to highly granular and custom criteria via data description and data ingestion APIs;
NuNet requirements: Data providers will have to provide the metadata for their data; NuNet will install NuNet adapter at each endpoint of the data provider for enabling and monitoring the appropriate usage;
Potential users: Individuals and organizations having useful but underutilized (due to privacy, security or commercial considerations) data sources;

[14] (i) data can be both open or IP protected – in which case property rights will be enabled via setting appropriate data sharing, provenance and security conditions; (ii) data is a part of computing, therefore in many real world use-cases a provider will offer both compute and data. Nevertheless it is necessary to separate these roles for the sake of technical and business model clarity. (iii) NuNet is collaborating with Ocean protocol for the purposes of building technical and business processes for the purposes of data ingestion and provisioning.

AI service providers

AI service providers are individual developers and organizations which register their services (AI, data science or ML workflows) to NuNet platform for enabling them to be executed on devices provided by compute providers, use data provided by data providers and discovered and used by NuNet platform consumers.

Demands: Maximize the usage of and returns on existing knowledge expressed in terms of AI algorithms, data science workflows, ML algorithms and general computing processes;
NuNet offer: Increased usage of and return on AI services by exposing them to larger customer base via NuNet platform;
NuNet requirements: NuNet will enforce ethical rules for AI services operating on the platform. AI service providers will have to provide metadata of their services to be used for discovering and matching them with requests of consumers (with the help of service ingestion, workflow aggregation and resource discovery APIs). Note, that most of the AI services may be provided not directly to NuNet platform but through the integrated platforms of the technical partners.
Potential users: AI developers, data scientists, open source software contributors and developers, software SMEs, decentralized computing frameworks and public / private computing clouds;

NuNet are partners with SingularityNET. AI services of global AI network built by SingularityNET will be the first AI service providers on NuNet platform.

Consumers

Consumers are individuals and organizations which demand machine intelligence, computing resources and data from NuNet platform and consume the results of business logic executed on the platform. Demands of consumers will be ingested into the platform via task description API. Results of completed tasks will be delivered to consumers via process validation and result description APIs. Payment gateways and aggregators will be used for the financial aspect of the interaction between consumers, providers and operators.

Demands: Business needs for AI services, data science workflows or general computing processes; data and computing resources for executing them;
Capabilities: Ability to define tasks to be carried by NuNet platform and receive and interpret their results. However, the majority of consumers of NuNet platform will most probably access the platform through integration with technical and business partners.
NuNet offer: Allow consumers directly, or AI algorithms automatically, to discover, use and pay for computing resources and data on NuNet platform, via task description, process validation and other APIs;
NuNet requirements: The only requirement by NuNet Foundation that will be the ethical usage of the platform; Ethical rules will be initially proposed by NuNet Foundation but later shaped by the community and sub-communities within the platform. By default, anybody will be able to access the decentralized platform in a generally unrestricted way and the best spirit of decentralized Web3 technologies. The universal monitoring and enforcement

of the ethical rules will be governed by the community following NuNet governance structure and enabled via verification and validation functionality of the platform[15].
Potential users: Individuals and organizations having complex computing and AI related tasks and business needs but lacking resources and knowledge to implement and run them using traditional means;

Network operators

Network operators are a special type of AI service providers which provide AI services and algorithms needed for the operation of the NuNet platform itself. In the beginning, NuNet Foundation will be the sole network operator and develop core network operating services and populate the platform with basic network operations agents. In the medium and long term, however, the ability to offer network operating services will be opened to third party developers. The long term goal of NuNet Foundation is to outsource the development of network services completely and concentrate solely on the development of API of APIs and the governance of the platform.

Demands: Earn return from AI services and algorithms making NuNet platform more efficient;
Capabilities: Ability to develop services needed by other users of the platform.
NuNet offer: Allow consumers directly, or AI algorithms automatically, to discover, use and pay for computing resources and data on NuNet platform, via task description, process validation and other APIs;
NuNet requirements: Network operating agents developed by third parties will have to be in strict compliance with the ethical rules and in line with the spirit and vision of the platform.
Entities: NuNet Foundation, open source software developers, software SMEs;

Since network operations agents will be a special kind of AI Services, NuNet will not build separate SDKs for building such agents, but rather will use the ones of technical partners. In beginning therefore, network operations agents will be built using SingularityNET's SDK and will constitute SingularityNET's AI services (which also could be made available on SigularityNET's marketplace).

Technical partners

NuNet aims to integrate the widest possible variety of computing frameworks and AI networks. Integration of current and future decentralized computing and storage frameworks, such as Golem, ANKR, Iagon, Enigma, iExec, SOMN, DFinity, Storj or Filecoin[16] and others will be strongly considered, but NuNet will also be very open to integrate traditional public cloud infrastructures as well, in order to fully cover consumer computing

[15] NuNet may create optional KYC mechanisms for integration into the reputation ecosystem of the platform and possibly for compliance with the indispensable legislative contexts in special cases and sub-communities within the decentralized framework.
[16] The list of prospective technical partners is indicative only and may change substantially in the future. No actual partnerships with the named frameworks, except explicitly indicated as such in this document, is as yet formalized or negotiated by NuNet at this stage.

needs. Majority of these frameworks have open APIs and are open source software themselves, therefore their integration may not need partnership on the development level. However, some frameworks will be deeply integrated into the core of NuNet and deeper technical partnership with them will be required and possibly backed by tokenomic integration via ERC-1155 type multi-tokens and cross-blockchain integrators, like Polkadot. Currently such a framework is SingularityNET. NuNet is also engaged in collaboration with Ocean Protocol and is planning to engage in partnerships with other DAIA members.

Technical partner's interests: Increase adoption and usage of the respective technology and
framework;
NuNet offer: Increase the exposure of partner's technology and framework to larger number of potential customers;
NuNet's interests: Maximize computing transactions on the platform and maintain steady growth; minimize business risks by not relying on a single computing platform or technical partner;

NuNet will establish an open ecosystem of competitive cooperation between integrated frameworks – a marketplace of marketplaces. Due to its openness, such cooperation would self-organize towards the best technologies and services, as valued by actual business requirements and consumers.

Platform developers

Platform developers are individuals which commit actual code comprising the platform code-base:

Core developers will comprise a small highly skillful permanent team financed by NuNet Foundation. Core development team will be responsible for guiding and coordinating technical development of the platform and will participate in the governance-principles;
Open source developers and contributors. NuNet platform development will be managed by the best practices of open source software development, attracting developers contributing to the NuNet platform code-base in the spirit of OSS. Some open source contributors may eventually become part of the core developer team which will be actively encouraged.

Core developers will be paid employees, but open source developers can be attracted and retained only with maintaining high quality, technically attractive and hackable codebase useful for diverse applications. Core development team will make sure that the NuNet platform codebase will be developed in this spirit from day one.

NuNet Foundation

The purpose of NuNet Foundation is to provide a legal basis for the NuNet platform, resources for the core team. Business goals of the Foundation are sustainability and growth of the ecosystem in the long term.

NuNet Foundation is a non-profit organization having no equity and equity rights. Core components of NuNet platform will be released under most permissive open source licenses (MIT, Apache or GPL - type) and will not be protected by IP rights. Nevertheless, users will be able to design and enable their IP-protected independent business models via NuNet platform by leveraging and combining the roles of compute-providers, data-providers, ai-service-providers providers and network-operators.

Partnerships and envisioned interoperations

The operation of NuNet will leverage the decentralized computing platforms and frameworks which it will support. Initially, the NuNet network will be developed with close partnership, technical and governance level coordination with SingularityNET and other members of Decentralized AI Alliance. NuNet will also seek partnerships with other decentralized computing frameworks and protocols, as rollout and community building proceed. Here are some of the partnerships and technical interoperations that are envisioned to be valuable as NuNet matures:

SingularityNET

SingularityNET is a decentralized platform for applied AI and AGI tools and datasets, which gives developers a way to share and monetize their creations. It is a tool for software developers across many vertical markets which lets anyone create, share, and monetize AI services at scale. SingularityNET aims at becoming a democratically governed 'decentralized self-organizing cooperative' when matured. External, non-AI Agents who wish to obtain AI services from Agents in the network will be able to contract them from SingularityNET's marketplace. Anyone using SingularityNET's Software Development Kit will be able to create a node (an AI Agent), put it online (running on a server, home computer, robot, or embedded device), and enter it into the network so that it can request and/or fulfill AI tasks in interaction with other nodes and engage in economic transactions.

NuNet will provide SingularityNET agents with access to the network of decentralized computing resources, computational reflection for optimizing resource capacities for specific Agents and economic mechanism for micropayments. Furthermore, NuNet will provide the architectural and logical layer necessary for SingularityNET Agents to self-organize into complex, dynamic and intelligent workflows.

Decentralized AI Alliance (DAIA)

Through the ability to support computational processes running within different decentralized computing and data sharing platforms of DAIA members, NuNet will provide a meta marketplace ecosystem which will allow to design data processing workflows that work across different decentralized platforms, private or public infrastructure of different owners of large and small scale computing resources.

Others

NuNet aims to integrate as many as possible currently existing and developed in the future decentralized computing and storage platforms on technical and tokenomic basis.

Tokenomics and governance

NuNet will be formally launched by a nonprofit foundation, the ***NuNet Foundation***. The Foundation will not have equity and equity rights, but will organize financing and management of launching the NuNet platform, expanding its operations and ensuring sustainable development of the ecosystem now and in the future. The Foundation will base its governance and management principles in line with the spirit, best available practices and expertise of Web3 movement and technologies, in compliance with available and evolving international legislation. Via the governance and management structure described hereby, the Foundation will manage technical development activities along the technical roadmap, provide required funds and resources via fundraising and crowdfunding activities, bootstrap internal tokenomics of the framework and ensure its transition to sustainable fully decentralized operation. The ***sustainable fully decentralized operation*** of the NuNet framework and platform is the ultimate mission of the Foundation.

Governance structure

NuNet Foundation will organize and build a decentralized governance structure of the network ensuring democratic and beneficial for all usage of the network and its sustainable development. Network governance decisions will be categorized into Minor, Major and Critical, where:

- ***Minor*** decisions are workaday decisions made in the course of operating the network;
- ***Major*** decisions are those with strategic importance;
- ***Critical*** decisions are those with potential large, direct existential impact to the network;

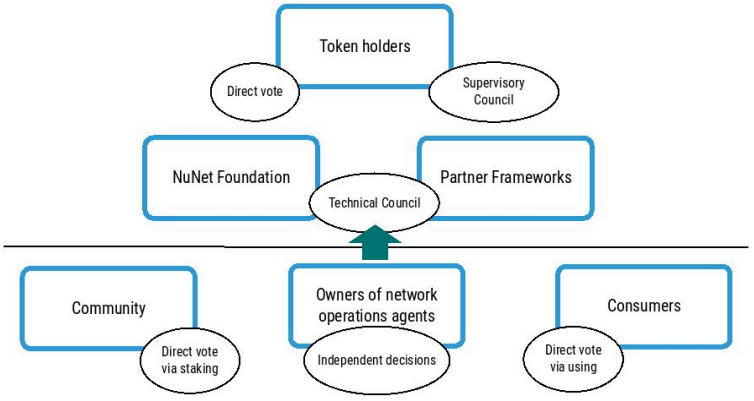

Figure 4: NuNet Foundation governance structure

Minor decisions will be made by the Foundation, partners or the pool of owners of network operations agents, depending on the case (initially the Foundation will be the only owner of network operations agents, so this distinction can be refined via consultation with counsel during the network's first years of operation). Foundation and partners will also elect a Technical council which may include representatives of owners of network operations agents.

In Years 1-3 following the Foundation's operation or before the NuNet platform network will become operational, NuNet Foundation will handle Major and Critical governance decisions as well, but the network will transition to democratic governance as it matures. Within the first year after the start of the network operation, a Supervisory Council of 3 members will be elected by the token holders, to serve an oversight and communication function on behalf of the token holding population. The intention is for the community to collaboratively make decisions regarding network operation, but for full democratic decision making to properly kick in only once the community has stabilized and matured to a reasonable degree.

In Years 4-5, Major and Critical governance decisions will require both approval of the NuNet Foundation, and vote of network participants holding a majority of the tokens held by all participants in the vote.

Beyond Year 5, Major network governance decisions (excepting those regarding Foundation activities that by law must be made by the Foundation's Board) will be made via a vote in which approval is given by voters holding a supermajority (60%) of the tokens held by all participants in the vote. Critical decisions will require a vote in which approval is given by voters holding a large supermajority (70%) of the tokens held by all participants in the vote.

Initially and before Year 4 of operation, the introduction of new network operation agents will be considered a Critical decision and approved accordingly. When the network matures and transitions to fully democratic governance, any party will be able to introduce new network operating agents, computational resources and data sources, given their compliance to legal requirements and Foundation's policy.

Foundation, partner frameworks and owners of network operation agents will propose the design of the subsequent developmental milestones, which will be evaluated and voted by the Technical council. Eventually, milestone releases and their development roadmaps will have to be approved by a larger community, service users and the majority of owners of network operations agents via independent decisions, staking mechanism and token purchase.

Initially the proportionality of fee distribution among owners of network operations agents will be simple: all fees will go to the NuNet Foundation, since all network operations agents will be owned by it. As new network operations agents are introduced, a scheme for dividing fees among owners of network operations agents may be approved via the processes for Critical decisions as defined above. The final goal of the NuNet framework and tokenomics development is to allow network operations agents, resource consumers and

users to ask and bid for resources in a competitive meta-market, where resources, intellect and knowledge will be directed towards socially beneficial tasks via democratic voting and individual staking.

Internal tokenomics

The tokenomics of NuNet platform is based on generalized mining of native cryptographic tokens and their distribution to constituents of the network in exchange for the active participation in network's operation and development.

The issuance of NuNet native utility tokens will be related to the amount of computational work performed within the network, following principles of generalized mining[17] and the quantity theory of money[18]. The total supply of tokens in the global economy of decentralized computing will be backed by the number of useful computational work and transactions carried out in the network at every moment, providing the fundamental basis for their sustainable value.

Generalized mining (also called Mining 2.0) is a mechanism where supply-side and other services are provided to the market by a third party in exchange for compensation of the network's native currency. Bitcoin's proof-of-work mining is the prototypical example of generalized mining, where miners compete to find a nonce value such that the resulting hash of the block header is below a target value. All Bitcoin miners, however, use the same algorithm in order to compete[19].

In contrast with distributed ledger technologies, like Bicoin, Ethereum and others, token mining in NuNet framework is not based on a single (yet distributed) algorithm nor requires global eventual consistency. In a decentralized computation framework that NuNet is, the consistency is required only at the local level of each computational workflow -- which could be wildly diverse -- while global consistency is not required nor desirable. NuNet will ensure the required local consistency via a set of smart contracts, governing construction, execution and dissolution of computational workflows and settling involved transactions. Naturally, tokenomic transactions between constituents of the NuNet framework will be performed on blockchains offering global eventual consistency and appropriate guarantees.

NuNet's tokenomic mechanism will combine the following aspects:

- A chosen ***measure of computing work***, consistently used by all compute providers registered in the network. NuNet network-wide telemetry information, supported by the Telemetry API, will necessarily include this information and will be used by network operations agents to quantify computational work involved in any specific workflow as well as by compute providers to quantify their capacities. NuNet

[17] Cambrial Capital, *Generalized Mining: the LPs perspective*. Token Economy Blog (November 10, 2018).
[18] https://en.wikipedia.org/wiki/Quantity_theory_of_money
[19] Other, more recent, examples of generalized mining based networks and supply-side markets are Livepeer and Filecoin.

Telemetry API will have the ability to calculate and return the measure of computational work involved in every transaction. This measure may be a combination of CPU, RAM, network usage, and disk storage units or a single unit of computational work such as [tera]FLOPS[20].

- ***Smart contracts***, implemented on all blockchains enabled by NuNet which will allow network operations agents to negotiate, lock and settle transactions related to computational workflows between components of the ecosystem. Initially, smart contracts will be written for Ethereum blockchain and work together with SingularityNET's platform contracts, but in the long term will expand to other blockchains and frameworks, as required by framework development. NuNet also considers leveraging collaborations with other frameworks and solutions, e.g. Ocean Protocol's Service Execution Agreements[21].

- A variant of the **proof-of-receipt** algorithm which will instruct smart contract to release funds reserved and approved in a contract binding all parties of a computational workflow only after valid results of the subscribed computational process are properly received and validated.

- A ***reputation system*** which will provide a basis for informal and community ecosystem driven verification, validation and trust of supply-side service providers. NuNet framework will provide guaranteed general mechanisms and information flows (Reputation API and Telemetry API) needed for reputation systems and their algorithms. Initially, NuNet will build a prototypical reputation system for bootstrapping the network operation; in the long term, however, the framework will encourage third party AI service providers to implement competing reputation systems as network operations agents and compete for best and most reliable reputation services -- eventually leading to a dynamically evolving ***reputation ecosystem***.

- The following ***payment logic*** implemented by NuNet smart contracts:
    - A considerable portion of computational workflows initiated within NuNet will involve crypto-token payments from consumers to providers via mediation of network operations agents;
    - NuNet will provide interoperability among decentralized computing frameworks and therefore transactions in native NuNet tokens will be closely related to transactions in native tokens of these frameworks. NuNet will provide a unified mechanism for executing multi token transactions (e.g. ERC-1155 based) that bundle NuNet token with all involved tokens/crypto-currencies so that it precisely matches the unique nature of each transaction.

[20] The NuNet network status demo application (https://stats.nunet.io/) showed how the combination of CPU, RAM, network bandwidth and disk storage metrics can be used for real-time network statistics and telemetry tracking. See Medium post on NuNet Platform Demo application for more.
[21] John Enevoldsen. Introducing the Ocean Protocol Service Agreements. Ocean Protocol Blog, Nov 29, 2018.

- The following **generalized mining logic** implemented by NuNet smart contracts:
    - A fixed amount of new NuNet tokens will be mined for each unit of computing performed by a validated computational process upon release of funds reserved for each transaction;
    - Newly minted tokens will be distributed to compute providers (most part), NuNet Foundation (as a form of 'network fee') and possibly other constituents of the network according to actual computational work spent on executing useful computational tasks. NuNet also may incentivize other supply-side services if considered necessary for facilitating the development and supply/demand balance within the network.

- The adaptive ***mining rate*** (i.e. amount of NuNet tokens mined relatively to completed computational work) which will initially be set to decrease on average by the factor of 2 in 2 years, roughly compensating for increase in computing efficiency[22]. To that end, in order to account for actual progress of computing technology and balance the NuNet tokenomy:
    - NuNet will create a frequently updated *composite computing price index* which will track the average price of computing on selected cloud computing engines and scientific computing platforms.
    - Initially, the index will follow a predetermined function (a variant of a bonding curve), which fixes the continuously decreasing mining rate;
    - An adaptive mining rate can be seen as an evolution of the 'halving' rate of Bitcoin. NuNet Foundation will adjust the mining rate as per above considerations in order to balance the supply and demand within NuNet ecosystem to the realities of the overall computing industry of the world. These decisions will be taken following NuNet's governance and management mechanism described below.

The NuNet internal tokenomics, combining proof of receipt, reputation systems, payment logic and generalized mining mechanism will ensure that new tokens are mined only if the physical computation actually happened, is useful for constituents of the workflow and the related payment transactions are approved. The mechanism is conceived to facilitate stable growth of the network via balancing supply-side incentives, token inflation and paying demand for decentralized computing resources. The mechanism will be flexible so that it allows context dependent adaptation and evolution facilitated by NuNet's governance and management.

Dynamic pricing and demand/supply dynamics

Via the tokenomic mechanism, compute providers in the NuNet network will compete for providing most cost efficient and reliable computing capacities for executing every

[22] Traditionally, computing efficiency was considered to follow Moore's law (showing that computing power doubles roughly in 18 months), recently being followed by Koomey's law (showing that computing efficiency doubles roughly at the same rate).

computational processes bidden by network operation agents. AI service providers will compete for providing most efficient and precise algorithms and AI engines. Data providers will compete for supplying best quality and most reliable data needed by AI algorithms. Network operating agents will compete between each other in their abilities to find best ways to construct computational workflows from data, computer resources and AI services and ensure their most efficient execution, clearing and settling of transactions on behalf of consumers, which will bid for actual work to be done on NuNet network. A successfully executed computational workflow will trigger a NuNet smart contract which will mine the amount of NuNet native tokens proportional to the computational work expended when executing the workflow.

In order to support the dynamic pricing of computational resources within the network, NuNet framework will:

- First of all, provide a composite computing price index, which will be available to all constituents of the framework in real-time via a native API. While prices of computing resources, charged by individual providers may differ from the index due to objective reasons (specialized capabilities, additional services, discounts / free support for socially beneficial computing projects, etc.), the index itself will serve as a global benchmark and a dynamic ‘bonding curve’, relating NuNet to the external market of computing resources and economy.
- The spot computing price in the network will depend on supply and demand dynamics of computing resources and could significantly vary depending on immediate circumstances.
    - This will introduce the supply / demand dynamics, so when demand exceeds supply, the average price of computing within NuNet network will exceed the price of computing 'in general', as measured by the index. New computing resources will be attracted to the network which will balance the price.
    - Additionally, the index will simplify transaction pricing, because it will introduce a simple measure according to which prices of different computational resources could be estimated and compared to each other -- which is essential for the network to work;
    - Within this framework, NuNet Foundation may introduce decentralized finance instruments, such as future trading, staking and others in order to facilitate market mechanisms for balancing compute price within the network and sustain growth of the network and token value;
    - Last but not least, the dynamic pricing of computing resources within NuNet will allow it to react in real time to surges of computing demand which may become a distinctive and important property of the framework as a whole[23].

Crowdfunding and token distribution

NuNet Foundation will attract resources needed for the development by generating initial supply of the utility tokens to be used in the operation of the platform (see Internal

[23] See use case On-demand computing resources for layer 2 technologies

tokenomics) and offering them to the individuals and organizations in the community, as per the technical roadmap and provisional timeline. Crowdfunding and token distribution strategy is explained in detail in the separate document.

Technical roadmap and early use cases

Initial technical roadmap

The scope and breadth of fully developed technical vision of NuNet's framework is highly ambitious and involves many tough problems to solve. The experience and knowledge of the initial NuNet team and further the management and governance structure of the project will be key going forward, both for guiding incremental development of the platform, and for revising the roadmap as lessons are learned and situations change.

The provisional roadmap provided here considers eight main aspects of development: 1) peer-to-peer network; 2) core APIs, description languages and data exchange mechanisms; 3) resource and process mapping; 4) meta-marketplace; 5) optimization and orchestration; 6) data sharing and provenance; 7) human/machine -- NuNet interface and 8) partnerships and technology integrations.

No. Functionality	Priority
1 Peer-to-peer network	
1.1 Interoperability between devices / resources	1
1.2 Interoparability between computational processes	1
2 Core APIs	
2.1 Resource description API	1
2.2 Computational process description API	1
2.3 Workflow design & description API	1
2.4 Topology API	2
2.5 Resource discovery API	2
2.6 Multi-dimensional value description API	3
2.7 Traceability and provenance API	3
2.8 Negotiation API	4
2.9 Reputation API	5
3 Resource and process mapping	
3.1 Manual mapping of processes to hardware	1
3.2 Automatic mapping	2
3.3 Open collaboration and self-organization	3
3.4 Logical scalability	4
4 Meta - Marketplace	
4.1 Bidding / asking mechanism for resources	2
4.2 Payment mechanism via the native token	2
4.3 Peer-to-peer negotiation language and contracts	4
4.4 Token exchange mechanism	2
5 Optimization and orchestration	
5.1 Execution introspection and performance monitoring	3
5.2 Resoure usage monitoring and tracking	4
5.3 Manual resource allocation via basic mobilitly	1
5.4 Automatic resource allocation via advanced mobility	4
5.5 Traceability of resource consumption	3
5.6 Cross-vendor cost tracing and logging	3
5.7 Advanced automatic optimization	5
5.8 Learning and meta-learning	5

No. Functionality	Priority
6 Data sharing and provenance	
6.1 Identity management	2
6.2 Security and privacy	3
6.3 Data provenance and traceability	3
7 Human/machine - Nunet interface	
7.1 Provider dashboard for managing resources	1
7.2 Application level user interfaces	1-5
7.3 User dashboard for managing costs and workflows	3
7.4 Interface between Nunet and human marketplaces	4
7.5 Automating and integrating all above	5
8 Partnerships and technology integrations	
8.1 Software Development Kit	2
8.2 Integration of computing environments/ecosystems -- SingularityNET	1
8.3 Integration of hardware providers	
-- Cloud providers	3
-- Single board computers	1
-- Mobile phones (Android)	1
8.4 Integration of data exchange protocols --Ocean, IPFS, etc.	1
8.5 Integration of decentralized storage -- Filecoin, Storj, etc.	4
8.6 Integration of micropayment infrastructures -- Ethereum, TODA, etc.	1

This provisional long-term functionality list is designed for iterative development. Each iteration / milestone of the development will be based on selected use case classes, so that when an iteration is complete and the network is updated, it will be ready for the real-world implementation of respective computational workflows. The iterative development strategy will enable the project to organically adjust to quickly changing technological landscape, partner technologies and ongoing innovations. The governance and management structure of Nunet is designed for empowering NuNet token holders, users and community to have a maximum say regarding network's design and operation decisions in democratic and beneficial way and during the whole implementation period.

The current NuNet development horizon covers the following milestones:

Development milestone	Implementation of tokenomics
1 Proof of concept	Internal within NuNet ecosystem
2 Basic testnet implementation	ERC-20 standard based on Ethereum blockchain
3 First mainnet implemenetation	Cardano Blockchain and/or ERC-20 on Ethereum

- Proof-of-concept (largely implemented) -- covering basic telemetry, resource and process description APIs and selected use cases and PoC point-based tokenomics;
- Testnet implementation -- featuring advanced tokenomics implementation and testing on Ethereum testnet on the basis of ERC-20 standard, selected PoC implementation of priority APIs and functionalities;
- First mainnet implementation -- featuring fungible tokens on Cardano or Ethereum blockchain (depending on development of respective technologies and partnerships), advanced implementation of further functionalities listed above.

Further development milestones will be designed iteratively to reach the full functionality as soon as possible, taking into account changing technological landscape, most relevant use-case implementations at time, and subject to NuNet governance decisions

Initially targeted use-case classes

Decentralized AI model ensembles

Training current state of the art machine learning models involving massive datasets is prohibitively expensive -- e.g. the specifically designed supercomputer for training OpenAI's costs over 250M US dollars[24], while the training of the model itself costs millions of dollars. Therefore, the development and application of cutting edge AI and ML technology for most researchers, individuals and SMEs is not affordable.

Researching, training and using AI and ML would become much more affordable and beneficial for society and the economy if latent cheap computing power of small personal devices, PCs and possibly mobile phones could be utilized to spread the computational work

[24] Riabinin, M., & Gusev, A. (2020). Learning@ home: Crowdsourced training of large neural networks using decentralized mixture-of-experts. *arXiv preprint arXiv:2002.04013*.

required to train such models. The underlying problem historically has been addressed by volunteer computing frameworks (e.g. BOINC) and projects (e.g. Folding@Home). However most of historic and to some extent recent volunteer or distributed computing frameworks are highly application specific, and also logically and/or architecturally centralized in the sense that there is a single server, node or a process which is responsible for the network's operation, distribution of workloads and aggregating results.

NuNet framework will allow for owners of latent computing resources to be compensated in cryptographic tokens, which will strongly facilitate participation of computing resources in the network, while still keeping them cheap and affordable for users. Furthermore, NuNet will enable truly decentralized cooperation and competition of AI models developed and trained by different researchers, individuals and possibly economic actors (initially via SingularityNET AI network and ecosystem). For example, participants will wrap their trained models into SingularityNET services and offer them in the marketplace. NuNet will enable these models to be run on laten computing resources supplied to the network and compensate each supplier according to their contribution. Furthermore, NuNet will allow data needed for training and updating models to be easily accessed and compensated.

Decentralized genetic-algorithm framework

As a first step toward supporting a rich variety of AI processing algorithms, NuNet will enable to coordinate decentralized and distributed optimization processes using Genetic Algorithms (GA) and Genetic Programming (GP). These algorithms are chosen because

- they are particularly well suited for a processing infrastructure consisting of a large number of processing units with widely varying capability (including some with very weak capability), loosely and erratically connected together;
- they are applicable to a wide variety of AI problems and optimization problems, applicable to a variety of practical and scientific domains.

This NuNet based GA/GP framework will support any genotype (solution space) and fitness function (objective function) fulfilling certain APIs, as is commonly done in OO genetic algorithm frameworks.

A specialized, simplified version of many aspects of the broader NuNet ecosystem would apply in this context:

- AI developers will contribute AI plug-ins to improve the GA/GP framework, e.g. specialized mutation and crossover operators, or EDA (Estimation of Distribution Algorithm) modeling tools or fitness estimation methods
- Applied AI developers will write code mapping specific types of practical real-world problems (e.g. predicting financial or climatological time series, designing certain types of machinery, extracting concepts from text, mining patterns in tabular or graph data, clustering data vectors, classifying genomic data, etc.) into GA/GP problems

- App developers will write NuNet apps using this AI code to solve specific problems, e.g. predicting aspects of climate change, recognizing patterns in ecommerce data, learning classification rules from genomic data about human disease, etc.)
- Users will be able to choose from among these apps, running multiple apps on their devices at various points in time, and in many cases receiving tokens as reward for their contribution of resources

The NuNet-based GA/GP toolset will support commercial services, in which apps provide value to customers who then pay for their services, with their payment ultimately resulting in tokens flowing to the NuNet resource providers. Payment may be made directly in NuNet tokens or in other tokens or (e.g. fiat) currencies via conversion gateways.

As NuNet framework will support staking resources, fiat and currency for socially beneficial services as defined and voted for by the community members, it will enable to use GA/GP to provide AI analysis for the common good, e.g. data analysis toward climatology or medicine. It will allow to run computation loads of certain socially beneficial but not necessarily commercially profitable and adequately funded projects on the framework. Additionally, NuNet Foundation may decide to provide bonus tokens to organizations using AI tools and computing resources for common good, so that they can adequately compensate resource owners; in this sense a GA/GP application would be used to experiment with tokenomic as well as algorithmic methodologies of post-monetary economy.

Bringing compute to data

Any computing, and especially state of the art AI and Machine Learning models, require huge amounts of data to process. Often the data is highly sensitive and/or protected by IP rights. Such data leaving the firewalled premises of the its owner is often impossible and leads to heavy inefficiencies in the data economy, where best AI / ML algorithms are unavailable for the high quality data and vice versa.

Thanks to the functionality of mobile computing processes, NuNet will be able to post any computing process (therefore any AI / ML algorithm) to any NuNet enabled datasource behind the farewell and ensure that no data will cross the firewall boundary. This will greatly increase the ability to use best available ML/AI algorithms for high quality data. NuNet is planning the cooperation and technical exploration with Ocean Protocol and other DAIA members for developing a general framework of mobile computing data and applying it to concrete business cases.

Dynamic data aggregation

Mobile computing processes may also allow to build distributed and decentralized databases and streaming data sources which combine a number of independent actors without requiring to fully expose proprietary data of these sources to third parties. For example, NuNet would provide a containerized program (local agent) for installation on the premises of a proprietary database owner (e.g. hospital of a pharma company). A container would accept external queries, pass them to internal database engines, collect answers,

anonymize / secure them and send data to a NuNet enabled AI engine where data from many local agents would be aggregated and processed. Alternatively, NuNet agents may expose browser plugins as micro-sources of streaming data from individual users, opening a myriad of use cases involving human computation and anonymized data collection (e.g. sentiment, opinions, fake news, text highlighting, etc.). Further, local agents may do part of pre-processing, accounting and payments. As a bonus, the mechanism would ensure that if relevant data changes on a local database, it becomes immediately available for all agents in the network.

Federated machine learning

The concept of *Federated Learning* was first introduced by Google in 2017 as collaborative machine learning without central data. Models are trained either from a starting point or from scratch using millions of distributed computing devices and their data. This approach is radically different from traditional, centralized training where the data and computational power are owned, operated and controlled by a single entity.

In the decentralized learning approach the device downloads a model by a resource consumer, then uses its own data to train this model and just send the result of this training step back. Leveraging the data and compute of the devices to be combined to update a model in the cloud. The updates are encrypted and not identifiable - the data remains anonymous and not traceable back to its origin.

This kind of machine learning system is a perfect use case for NuNet and its goals. To realise this quickly we will leverage existing federated training frameworks and include the NuNet adapter into them. This will make it possible to leverage NuNet and all its participating devices for commercial and common training of AI models.

The models can either be single-party, multi-party or a common system. An example for a single-party system would be a music recommendation service where the model is adapted using the individual choices but after a certain number of choices and model updates the result is communicated back. Here the funding of the resources distributed to the participants would be invested by the single-party.

A multi-party system could be a fraud detection system of multiple financial partners that are sharing a resulting models but don’t want to expose their individual data sets. Another use case of this would be an autonomous driving model that is shared by multiple cars from multiple vendors but updated on the data of all of them. The funding of the compensational resources is done by the involved parties.

A common system could be a climate prediction model shared and updated by all humans interested in stopping climate change. Other common models could be a medical system to predict and prevent diseases trained and shared among all of humankind. The participants can donate their resources to achieve a greater good without having to spend money but instead leveraging their mobile phones and power but most importantly their time and data.

This kind of training adapts the model and possibly the application using it on the device to the data of the individual user - thus resulting in a hyper personalized model where the input of the individual becomes an update for the model of the whole.

Health data pre-processing and sharing

The health wearables device market is booming with double-digit annual growth rates, expected to reach 450 million shipments by 2022[25] and amount to $60B market by 2023[26]. Health wearables become parts of patients' treatment plans, insurance companies' policies and individual lifestyles. The amount of data collected globally by these devices increases even at higher rates.

However, data privacy and consent are continuing to pose significant barriers to the realization of the myriad opportunities offered by individuals' health related data in the domains of patient monitoring, longevity therapeutics, predictive, preventive, personalized and participatory medicine and medical research in general. Providing continuous aggregation, processing and mining for data collected via multiple devices from different vendors is an unresolved engineering and management problem. Unlocking this potential is paramount for human society and civilization on many levels, solutions towards which contain tremendous social, business and personal value.

Data sharing among individual health wearables is currently very limited -- each wearable provides only certain types of sensors and information but not other, i.e. heart rate, step count, blood pressure, sleep cycle, etc. This information is usually stored in a private cloud, which is accessible and shareable only among users of the same provider or device manufacturer. Medical research and precision medicine however is based on the integration of all these types of data which, currently is based on sharing databases on the provider level. Furthermore, predictive, preventive, personalized and participatory medicine (P4) needs integration of other types of data, including genome sequencing, electronic medical record and more.

The core architecture of NuNet provides a platform enabling effective management and enaction of decisions regarding data sharing, processing, storage and anonymization, where these decisions may happen at the level of the individual human or device. Specifically, in the NuNet approach:

1) Fitness data of each device is recorded and stored in a local database or cloud as the application of a device provider allows;
2) NuNet adapter is installed on every individual device (e.g. smartphone or tablet) where fitness data is stored. The adapter exposes NuNet APIs for resource description, traceability and provenance, resource and data discovery and others;

[25] Gartner (November 29, 2018) Gartner Says Worldwide Wearable Device Sales to Grow 26 Percent in 2019.
[26] Business Wire (January 14, 2019) Juniper Research: Healthcare Spend in Wearables to Reach $60 Billion by 2023, as Monitoring Devices & Hearables Become 'Must Haves' in Delivering Care.

3) Using these APIs each device announces the availability of certain types of data to other NuNet enabled devices; Using the same APIs, healthcare service providers and data aggregators announce their services;
4) Healthcare, personalized and precision medicine providers, longevity therapeutics and medical researchers use NuNet-enabled devices to find data sources, sign contracts, provide micropayments for personal data usage and offer their services in terms of personalized advice and analysis;
5) Health wearable users can search for service providers and additional knowledge that can be retrieved from their data. Alternatively, they receive notifications about offers from service providers which they may accept or reject at any moment, retrieving their personal data;
6) NuNet enables data pre-processing and anonymization at user's device by decentralizing data processing workflow and installing parts of it to device where data is. In this way it ensures that private data never leaves a device in the first place.
7) Service providers, which use proprietary or open source algorithms for data analysis and aggregation, leverage decentralized computing framework of NuNet to bid for free computing resources available at mobile devices which may or may not correspond to the ones that provide data.
8) Individual data and compute resource providers establish formal digital relations with data aggregators and compute resource users via the smart contract mechanism. Smart contracts can involve any type of barter (data for analysis, compute resources for data) exchange or micropayments. Canceling a smart contract ensures that the data is not accessed by third parties any more.

Secure data exchange in decentralized systems

The complex problem of ensuring security of IoT ecosystems is the biggest obstacle to large scale IoT adoption and integration into business models. Furthermore, data privacy, provenance and high granularity access management, while being instrumental for unlocking the potential of data economy, hits new levels of complexity in decentralized IoT systems where "firewalls" have to be distributed across a large number of devices, most of which are too low powered to run full operating systems or an Internet protocol stacks. IoT security systems have to be decentralized by design, without a single trust layer or a trusted party. Ability to customize and integrate blockchain and state-of-the art trusted computing technologies in decentralized computing workflows on NuNet framework allows solution providers to address many obstacles of IoT adoption by design at case by case basis.

Flexible decentralized computations at the edge

NuNet leverages computing frameworks of its partners by allowing to build flexible and radically decentralized computation graphs spanning IoT devices of different capacities and owned by different economic players and community members -- simple or advanced sensors, robotic microcontrollers, embedded systems, virtual machines on the edge, fog and cloud. It enables to design efficient and fast data and AI workflows for dynamic IoT environments where huge amounts of streaming data can be processed as close to the edge as required by the business model and capacities of the particular system. In the

future, NuNet and SingularityNET are planning to partner for implementing technologies required for the automatic adaptability for balancing computing loads in IoT networks in real-time.

Mobile IoT device ecosystems and smart-city implementations

Mobile IoT device ecosystems, such as sensors and cameras equipped drones, cars, smartphones and in general more or less advanced autonomous robots provide implementation challenges simply due to the fact that their topologies constantly change. Furthermore, network connectivity speeds and patterns may change considerably when components of the network move with respect to each other. NuNet, leveraged by AI ecosystem of SingularityNET, provides the ability to balance computing loads between the edge and 'core' of such networks and subnetworks thus supporting diverse mobile or stationary IoT device ecosystems, such as semi-autonomous rescue and security drone fleets, car fleets, collaborative robots, truck platoons, etc. Furthermore, NuNet elables cross-vendor cooperation via its tokenomics mechanism, allowing to integrate devices and ecosystems of different vendors into a single computing workflow.

Cross-vendor process integration

Decentralized by design computing architectures and data workflows of IoT networks, which span large geographical areas and involve diverse ecosystems of individually secured devices, allows solution providers to integrate devices and computational process owned and operated by different businesses into a single business process. Using blockchain based custom state-of-the art data privacy, provenance, access management solutions and an economic mechanism powered by fine-grained microtransactions, NuNet and SingularityNET enables data economy and business ecosystems with many partners that do not need to be centrally managed or rely on a single trusted party. The capability of integrating multiple vendors and businesses into one value chain has huge potential in largely untapped IoT domains such as smart city, international supply chains and management of large partnerships in general.

On-demand computing resources for layer 2 technologies

A somewhat unexpected but potentially highly valuable application of NuNet framework is its ability to provision on-demand computing resources to applications built on blockchain layer 2 technologies. For example, decentralized exchanges (DEX) are suffering the same scalability and speed issues as the underlying blockchains and are orders of magnitude slower than their centralized counterparts. While DEXes solve the scalability and speed issues of real-time matching by different designs from centralized exchanges, speed and scalability will remain an important factor for the development of DeFi industry. Upcoming layer 2 technologies (e.g. Ethereum Plasma) will allow offloading computing from the main blockchain to side chains and in this way increase its scalability. Exchanges are known to experience surges of high-frequency trading and low-latency arme races which are quite rare and require a lot of spare computer power to be provisioned by centralized exchanges

[27]. Decentralized exchanges, however, may allow high speed traders to acquire speed and computing power from peer-to-peer networks, such as NuNet, on demand. NuNet's in-built dynamic pricing of computing resources may provide economic mechanisms for computing resources to be allocated where there is a need.

Large partnerships

Automating supply and delivery chains are special cases of business processes involving large number or independent economic entities which for technological, economic or competitive reasons cannot be coordinated in a centralized manner (e.g. competing shippers may not want to subscribe or trust a centrally managed database owned by a large competitor), yet the coordination and real-time information exchange would clearly benefit all participants of the ecosystem. Secure distributed trust technologies combining public and permissioned blockchains may be integrated to IoT and AI processes for supporting diverse business models and commercial collaborations which were not available before (e.g. in smart power grid management, connected houses, utility management, etc.). A global decentralized computing framework of NuNet provides a technological basis for building such collaborations and computing workflows, leveraged by SingularityNET and other partner's ecosystems.

[27] Brolley, Michael and Zoican, Marius, Liquid speed: A congestion fee for low-latency exchanges (May 22, 2020). Rotman School of Management Working Paper No. 3377346, European Finance Association 2020 Helsinki.