PDS^2: Privacy-Preserving Decentralized Data Sharing System

Presentation by Lodovico Giaretta

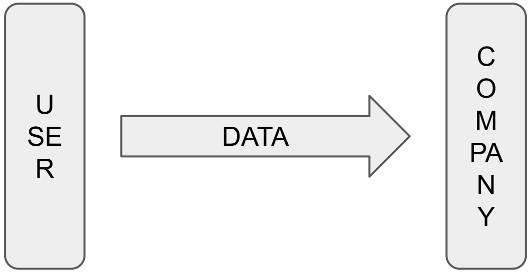
PDS^2 is a project by Lodovico Giaretta, Ioannis Savvidis and Thomas Marchioro

Motivation

The Problems of Data Collection

Data Analysis and Machine Learning **drive value generation** in many sectors

Thus, data collection and exploitation are **fundamental for business** success



For the user:

❌ No **control** over the data
- Can't control when, how or by who it is used

❌ No **privacy** guarantees

❌ No **reward** for the value generated

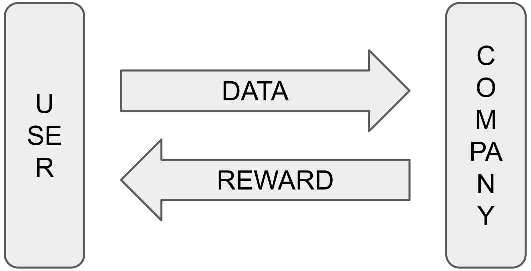
For organizations:

❌ High **barriers to entry**
- Small orgs cannot compete without data

❌ **Legal burdens** due to sensitive data

❌ **Infrastructural costs** for data analysis

Existing Data Marketplaces (mostly for IoT)



For the user:

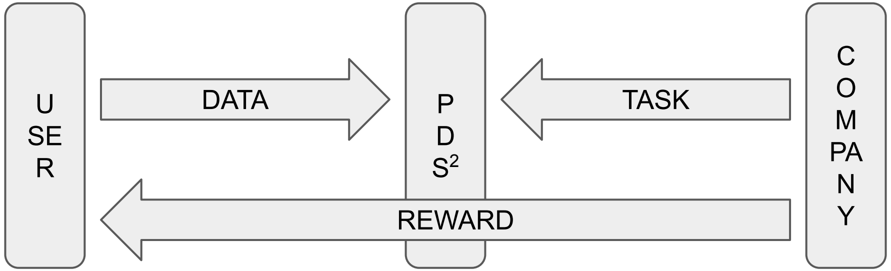
- ❌ No **control** over the data
  - Can’t control when, how or by who it is used
- ❌ No **privacy** guarantees
- ✔️ **Rewards** for the value generated
- ❌ Often no **user-centered** design
  - Designed for SMEs as data producers

For organizations:

- ✔️ Lower **barriers to entry**
  - Can more easily access any available data
- ❌ **Legal burdens** due to sensitive data
- ❌ **Infrastructural costs** for data analysis

PDS^2 Properties

someone needs to run this!



For the user:

- ✓ Full **control** over the data
  - Need explicit permission for each task
- ✓ Strong **privacy** guarantees
  - Organizations do not directly see the raw data
- ✓ **Rewards** for the value generated
- ✓ **User-centered** design
  - Designed with individual users in mind

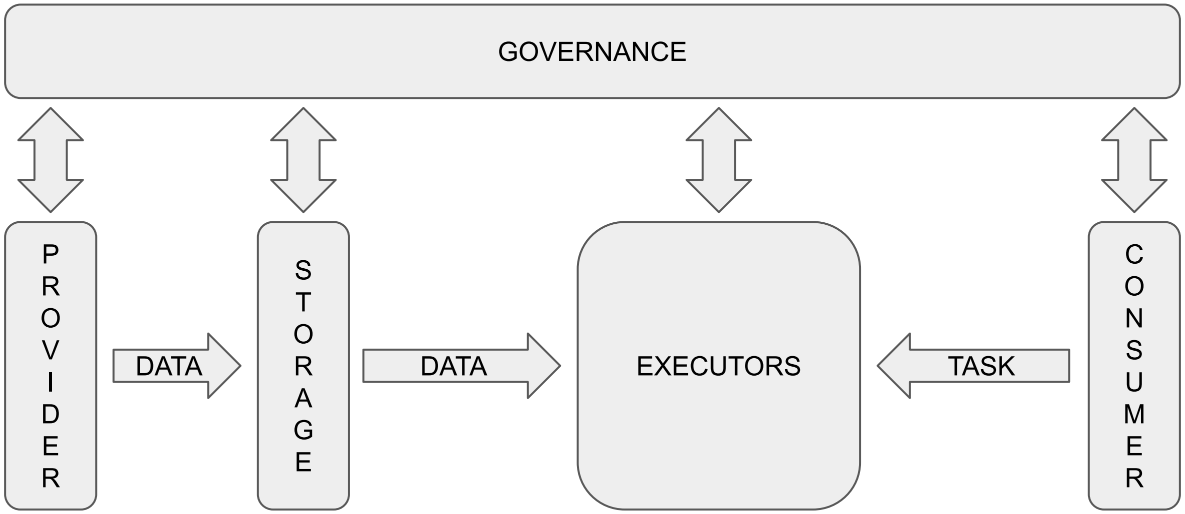
For organizations:

- ✓ Lower **barriers to entry**
  - Can more easily access any available data
- ✓ No **legal burdens** (no direct data access)
- ✓ Lower **infrastructural costs**
  - Tasks run remotely in the marketplace
- ✓ Strong **intellectual properties protections**
  - Tasks and results invisible to other players

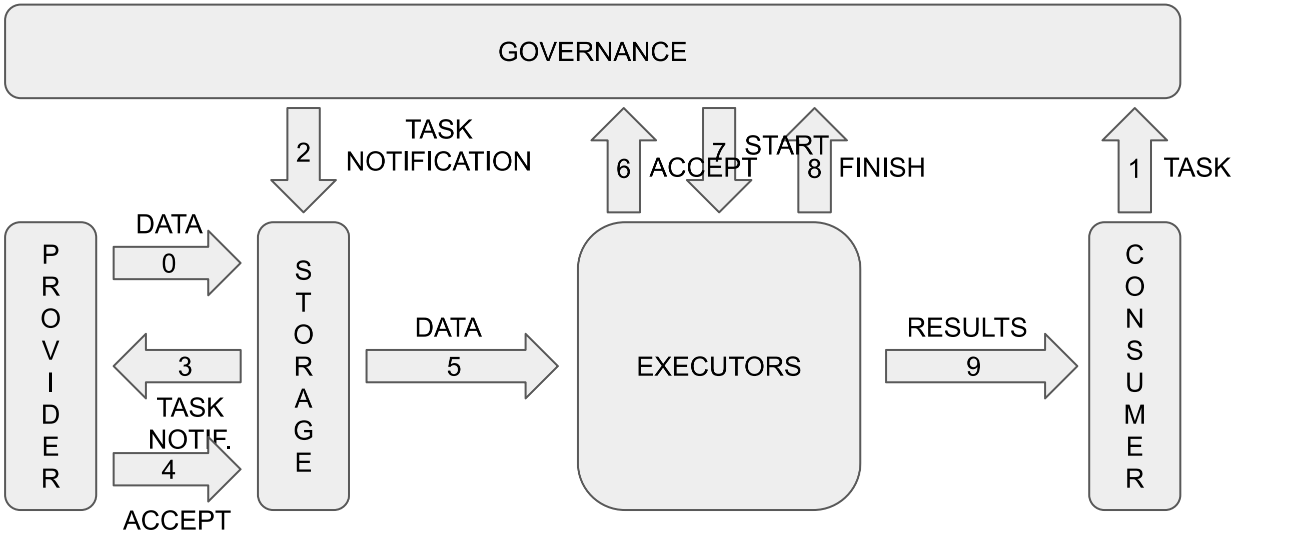
For the infrastructure maintainers: ✓ a share of the **rewards**

PDS^2 Architecture

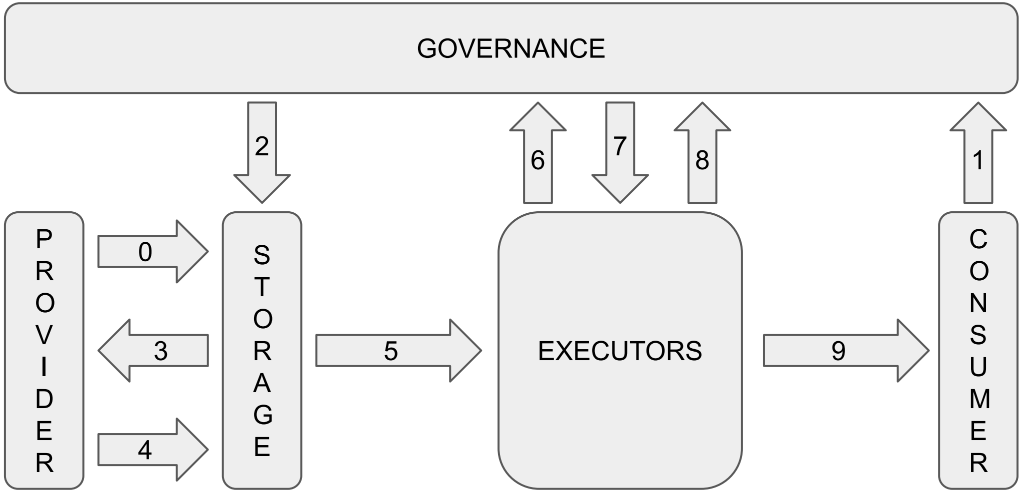
General Architecture



Task Workflow



Task Workflow



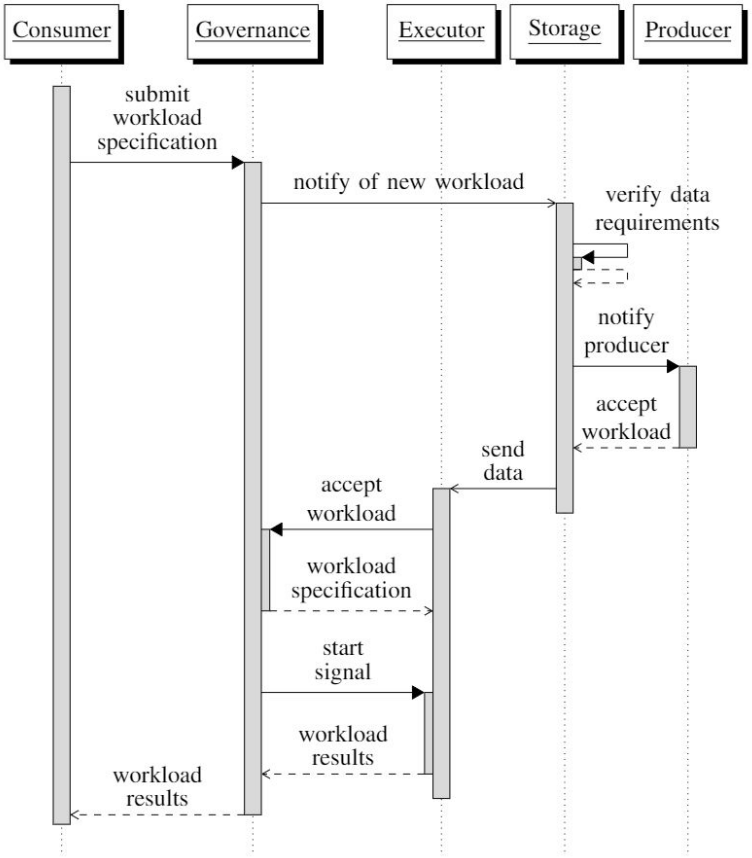


Fig. 2. Sequence diagram of the high-level interactions during the lifetime of a workload in PDS^2.

Modular Architecture

Configurable Aggregation Strategy (**Gossip**, Federated, Hierarchical, ...)

Configurable Storage Solution (Local, Cloud, Decentralized, ...)

Data-independent

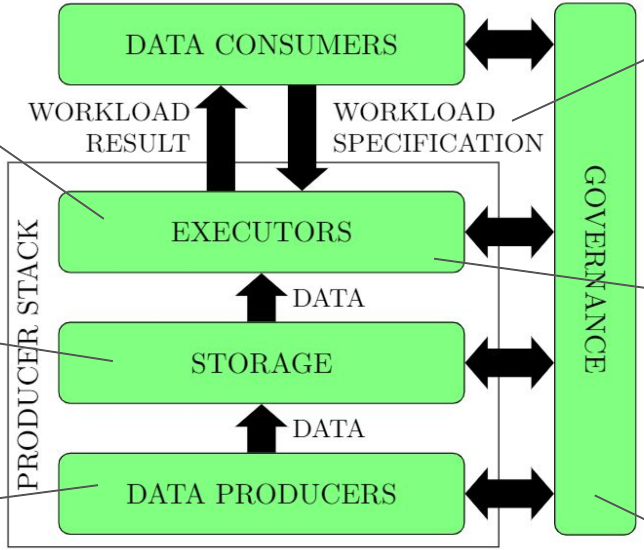


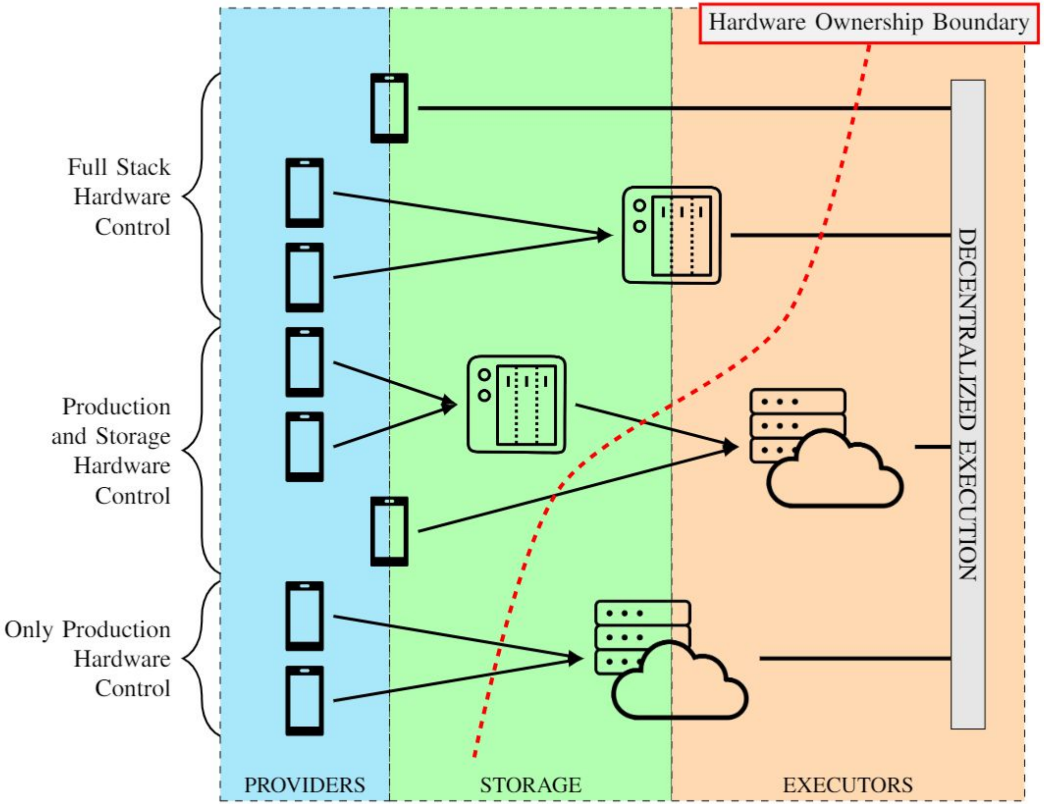
Figure 1: High-level architecture of PDS²

Supports any data aggregation task (with caveats)

Configurable Privacy-Preserving Execution (**TEEs**, Homomorphic Encryption, ...)

Configurable Governance System (**Ethereum**, other blockchains, Trusted Entity, ...)

User-Centered Flexibility



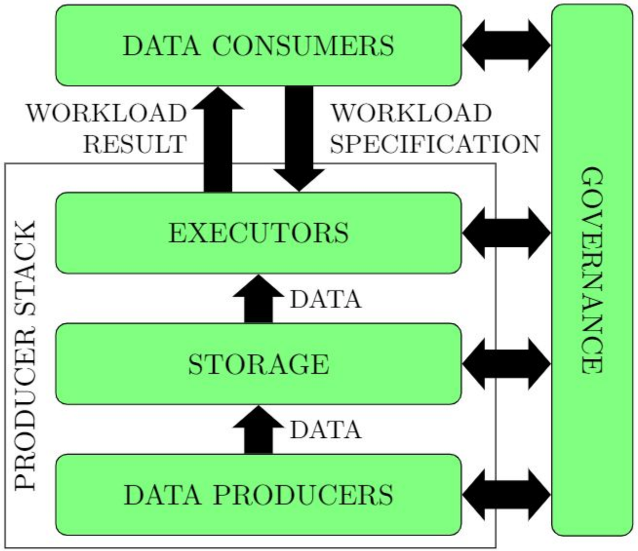


Figure 1: High-level architecture of PDS^2

Building Blocks

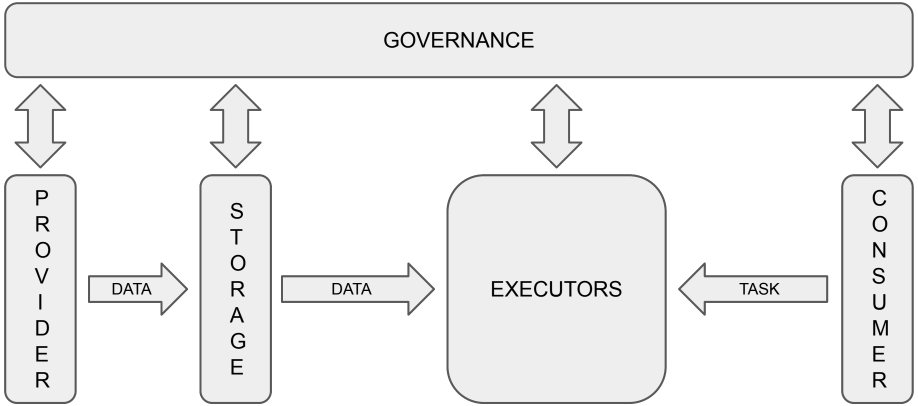
Privacy-Preserving Data Processing

Two types of **private information**:

- Providers' **data**
- Consumers' **intellectual properties** (e.g. code)

Must be **inaccesible to anyone else**

- Including the providers' own storage layer
- Including the **executors** that run the code



Solution: use **encryption**!

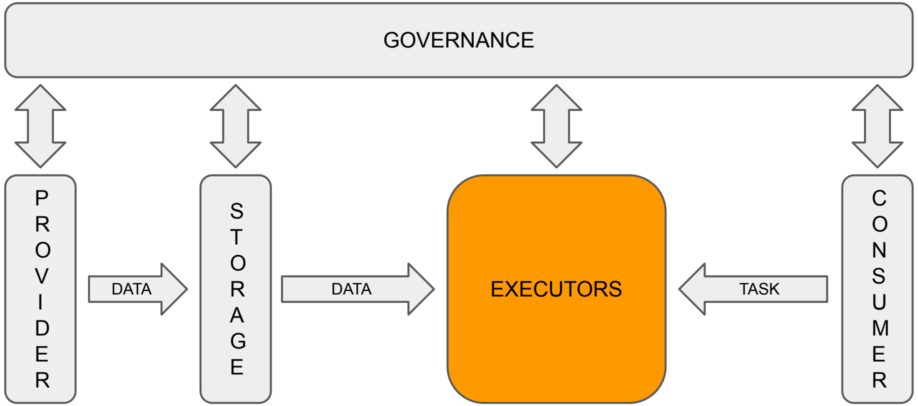
Problem: how can the executors **perform the task, without seeing the code nor the data?**

Solution: **privacy-preserving data processing**!

Trusted Execution Environments

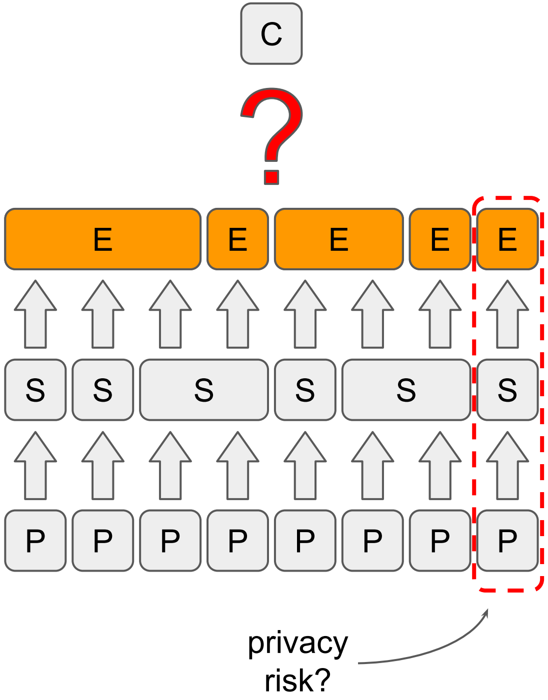
Isolated, tamper-proof hardware black boxes

- Impossible to see what is inside them
  - Even for the owner
- All outside communications are encrypted
- Possible to verify that the correct code is being run
- Just need to trust that the TEE is secure
- Widely available in Intel CPUs (Intel SGX)



TEEs are the most suitable privacy-preserving data computation technique for PDS[2]

Decentralized Aggregation



Each executor can only compute **partial results**.

Problem: how do we merge them?

Solution 1: let the consumer do it! (e.g. Federated Learning)

- Scalability issues
- Fairness, transparency, auditability issues
- Privacy issues

Solution 2: **decentralized aggregation**! (e.g. Gossip Learning)

- Peer-to-peer protocols based on gossip communications
- Efficient usage of all available resources
- Runs on the executors (privacy-preserving data processing)

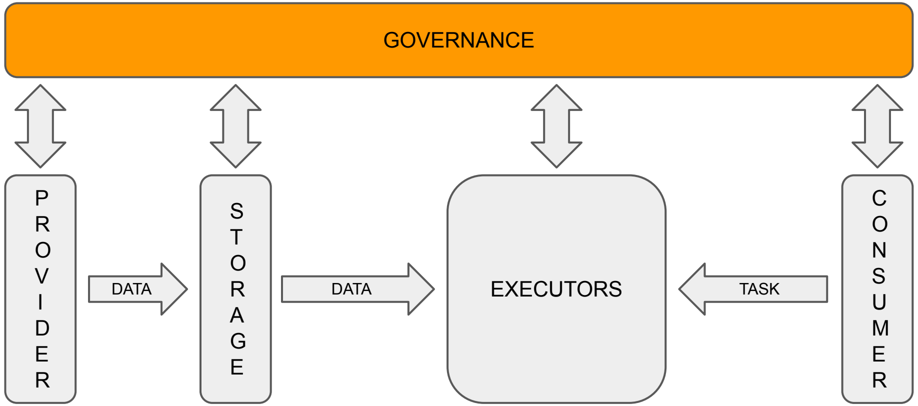
Gossip-based aggregation is the most suitable technique for PDS[2]

Blockchain Technology

Natural solution for **decentralized governance**

PDS² requirements:

- Complex **smart contracts**
  - Manage the workflow of each task
- **Non-fungible assets** management
  - Unique, indivisible assets
  - E.g. data chunks, code
- **Fungible assets** management
  - Divisible, indistinguishable assets
  - E.g. currencies, reward tokens



Ethereum provides all of this, along with a vast, mature ecosystem

Ethereum is the most suitable blockchain for PDS²

Open Challenges (1)

Rewarding Schemes

- Same reward for all participants? Reward based on amount of data?
  - Is it fair? Is all data worth the same?
- Reward based on the “added value” of each provider?
  - Computationally expensive; reward not known until the task is finished

Data Authenticity

- Prevent providers from forging fake data (useful for extra rewards!)
  - Possible with cryptographic signatures?
- Prevent users from replicating their data
  - I.e. send multiple copies of the data to different executors, to increase their rewards
  - Preventable with blockchain validation of non-fungible assets?

Open Challenges (2)

Indirect Privacy Leaks

- Certain consumer tasks might leak too much user information (maybe even on purpose!)
  - Static / dynamic task analysis to detect this?
  - Indiscriminately inject noise in the results (i.e. differential privacy)?

Data Discovery and Filtering

- Storage subsystem uses metadata to identify eligible data for each task
- “I want Fitbit data of people running when ambient temperature was less than 5°C”
  - Fine-grained metadata implies privacy leaks
  - Even participation in the task implies privacy leaks!
- Let the executors do the filtering?
  - Computationally expensive; eligibility and rewards not known in advance

Conclusions

PDS^2 in a Nutshell

A user-centered decentralized data marketplace for privacy-preserving data processing

Not reinventing the wheel: built on existing technologies, bringing together different research areas

Driven by user requirements: evolved from a simple sketch, growing to accomodate all needs

Modular, flexible and extensible: because technologies and needs constantly evolve

Project Status

Current Status:

- High-level architecture and interactions fully defined
- Most suitable technological solutions identified
- Vision paper drafted, to be submitted for peer-review on Jan 25

Future Directions:

- Proof-of-concept implementation
  - Test overall feasibility of the architecture
  - Evaluate different technologies for each component
- Follow-up work on each separate component
  - Modular design allows parallel work on different aspects
  - Each of us will work on a specific component, based on personal expertise and interest
  - Anyone can design additional components or different implementations!

Any Questions?