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Chapter 10: Future Directions in Autonomous and Self-Governing Data Platforms

10.1. Introduction

As vast amounts of data are generated, complex infrastructures are formed for storing, processing, exchanging, analyzing, and visualizing data across heterogeneous organizations. Despite the potential of industrial data ecosystems, collaboration remains a challenge due to the need for access to sensitive data, lack of established trust relationships for data-sharing and uneven incentive structures. Therefore, a direction toward the emergence of autonomous and self-governing data platforms, the work addresses research questions. The two proposed concepts—defined—are motivated by the desire for full automation of the data value chain and by the special requirements of the financial and healthcare sectors. The first concept seeks to automate technical processes and organizational relationships, while the second aims at automating the establishment, management, and dissolution of data-sharing agreements, enabling a "marketplace-like experience" for data sharing.

Autonomous data platforms, applied in healthcare, provide an environment for deep learning models to operate in a decentral manner without requiring mutual data sharing. Self-governing data ecosystems focus on optimizing data-sharing agreements among actors in the finance sector, and the new concept promises significant reduction in costs, risks, and time consumed in the data-processing chain. Foundations are detailed, complemented by supporting technologies such as privacy-preserving computation, compliance by design, and federated learning, and a range of challenges—spanning reliability, auditability, accountability, and explainability—are distilled.

10.1.1. Autonomous Data Platforms in Healthcare

The vision for autonomous platforms—supported by main-streaming AI technologies—capable of operating a large volume of data directly from the edge of the data value chain

is beginning to take shape and can be exemplified in the healthcare domain. Several major cloud service providers, semiconductor manufacturers, and a host of start-ups envision using AI infrastructure to scale the intelligence needed to automate the orchestration of large volumes of data and data processing resources between edge regions and dedicated AI services. In healthcare, it is expected that core decentralized AI (Federated Learning, Federated Inference, Federated Transfer Learning) and data algorithm-sharing capabilities will come of age first due to the particularly intense business and societal drivers to ensure data privacy, impose strict compliance regulations, create ethical concerns, prevent targeted advertising, avoid bias, and, at the same time, remain competitive. Therefore, a data value chain that maintains sensitive health data within hospitals and health authorities, executes algorithms at these sites, and shares only the trained models promises to find early-stage deployment in the medical domain.

Curbing the financial fraud that is draining the economy and exploiting wealth redistribution mechanisms remains a high priority in society. As the Internet has bypassed traditional barriers, money laundering, financial fraud, terrorist funding, securities fraud, and tax avoidance are global threats and problems. In particular, the conventional data sharing model for detecting financial fraud is inherently weak due to the strict confidentiality requirements, especially for competing financial institutions. Privacy-preserving techniques (e.g., cryptography, differential privacy, secret sharing) can help enable cross-organizational collaboration in almost real-time while protecting sensitive information. A self-governing data ecosystem that allows privacy-preserved data sharing for detecting finance-related fraud can therefore provide a solution-oriented approach.

Fig 10.1: Future Directions in Autonomous and Self-Governing Data Platforms

10.1.2. Self-Governing Data Ecosystems in Finance

In finance, growing complexity across business units and ecosystems impacts data governance and compliance. Differentially private machine learning and selective encrypted searches allow the application of advanced data science in federated settings, while a regulatory compliance-as-a-service (RCaaS) platform leverages privacy-preserving multi-party computation. Combined with risk-based algorithmic auditing, these approaches advance data analytics capabilities while addressing evolving regulatory requirements. Regulatory bodies are turning their attention to crypto-assets. Despite claiming to operate outside the traditional financial system, many firms in the crypto space have grown into complex financial services ecosystems serving significant amounts of users. Regulators are developing new rules to hold crypto firms to the same standards as traditional financial services.

Achieving such an outcome in crypto will require assessing risk and allocating resources accordingly. Building a regulated crypto environment controlled by regulated entities and APIs to share information will help mitigate concerns about the industry's impact on financial stability, sovereignty, and tax compliance, while protecting consumers. Novel forms of systemic risk and contagion via new interconnections within and with traditional financial systems must also be addressed. A tailored regime combining existing regimes will be needed for decentralized finance, addressing the distinct financial stability risks. Governments must also find an appropriate approach to central bank digital currencies giving due regard to risk and prudential concerns.

10.2. Foundations of Autonomous Data Platforms

The creation of autonomous data platforms that support innovative knowledge discovery and commercial operations over sensitive, fully autonomous data assets involves a three-level architecture. At the lowest level, different kinds of AI-Enabled Data Platforms combine advanced artificial intelligence technologies for the autonomous and orchestrated execution of complex workflows while taking into account domain knowledge and the distinctive traits of a specific platform. At the second level, AI-Enabled Marketplace Ecosystems provide a storefront for modular services that deliver different privacy-enhancing operations within workflows and different service compositions. Operation services can freely choose how to combine such market operations into complete workflows, which operate over the mission-tuned homomorphic-encryption keys owned by the region—thus safeguarding privacy by design and letting the operations be executed at south data layers, near the data sources themselves. A self-governing marketplace architecture for privacy-preserving cloud-computing services in financial domains is also conceived. Credit-risk models trained

on privacy-preserving data clearly outperform traditional models, thus opening the way to practical implementations with real operator settings.

The third level embodies self-governing data ecosystems, which bring together a possibly large consortium of data agents aimed at supporting multi-party intelligence and simulation tasks. Autonomous and iterative components supervise all stages of the ecosystem life cycle, thus autonomously bootstrapping the community, managing the regular operations, and enabling possible extensions to new data sources. The bootstrapping phase shows how a one-shot auction of an initial set of data taxpayers can be followed by sequential community extensions, with the rightful incentives for newcomers. Different self-governing data systems are being considered. First examples deal with federated-learning tasks for health data analytics, with an emphasis on privacy preservation during the whole community life cycle. A self-governing marketplace ecosystem for finance applications represents another important direction.

10.2.1. Architectural Principles

The architectural principles that underpin Autonomous Data Platforms (ADPs) must address opportunities and challenges emerging from self-governing governance mechanisms. Concurrently, these principles must promote the incorporation of novel autonomic processes at all levels of the architecture, ranging from the meta service layer through the platform service layer to the data service layer.

The emerging virtually autonomous data platforms are characterized not only by self-governing mechanisms that support decentralization of governance and management but also by decision-making and orchestration mechanisms, such as workload and service placement, which are increasingly driven by artificial intelligence. The next logical step is to enable decentralization of operations based on real-time AI-driven decisions, through the integration of the operability module, responsible for monitoring the platform operation and reacting to events, into the meta service layer of the autonomic architecture for data platforms. An additional compelling reason to consider virtually autonomous data platforms is the growing concern about data governance, privacy, security, and industry-specific compliance regulations. The creation of mechanisms that alleviate data security and privacy concerns and offer sufficient levels of confidentiality, even when the data is placed in the custody of a third party, is becoming a necessity.

10.2.2. Autonomous Governance Mechanisms

Autonomous data orchestration in autonomous data platforms requires artificial intelligence (AI) and machine learning (ML) solutions that follow established

architectural principles. Diverse AI-based capabilities are demanded, such as predictive models for the expected distribution of data queries and data management tasks (data ingestion, preparation, cleaning, integration, and data persistence). Orchestration algorithms must autonomously balance and allocate the available resources while serving the expected workloads. Nevertheless, the classical allocation mechanisms based on queuing theory do not guarantee an optimal allocation for the overall system. To achieve this goal, it is necessary to adopt a global perspective based on Game Theory. Well-established algorithms such as the Improvement Algorithm can be incorporated to steer the optimally distributed resource allocation. A model to predict the expected influx of data requests and data management tasks can be used to find the optimal time to decide the resource allocation and thus give a clearer indication to the workload orchestration.

The autonomic management of Data Platforms and Services requires, above everything else, that the execution decisions can be taken by an artificial agent without human intervention. Specifically, humans must not define any policy or strategy to direct the behavior of the platform. This is contrary to the approaches adopted in TOSCA and similar languages that incur overhead from human intervention and maintenance. The introduction of a new concept called Not Need Specification (NNS) defines the characteristics of an instance of a service or platform that guarantee autonomic management at any level. Thus, it is solely the internal behavior of the agent that guarantees the autonomic management without human intervention at any level, ranging from the behavior patterns of its services to the temporal dimension.

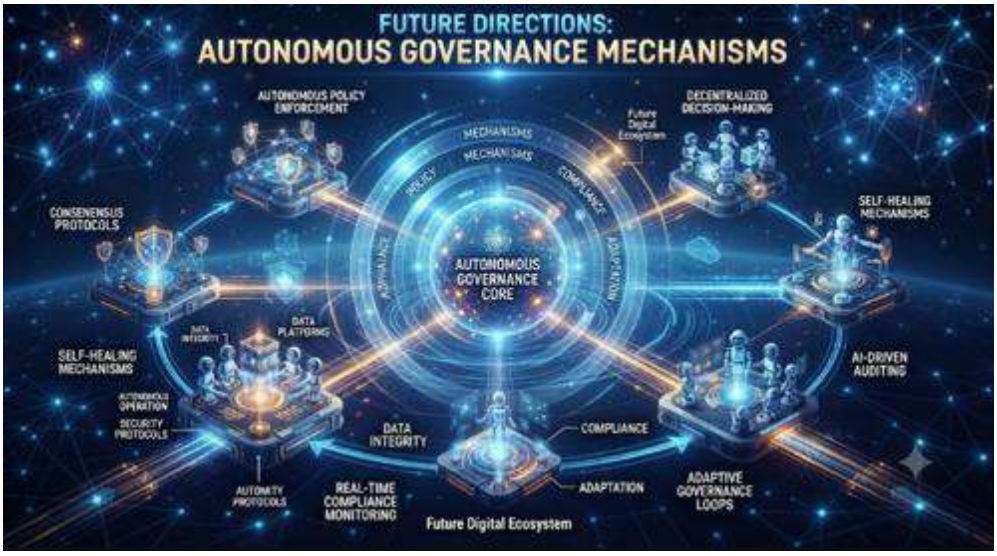

Fig 10.2: Autonomous Governance Mechanisms

10.3. Enabling Technologies and Paradigms

Autonomous and self-governing data platforms are made feasible by evolving technologies and paradigms, such as AI-driven data orchestration and decision-making, privacy-enhancing computation, and compliance by design. Autonomous platforms benefit from integrated fully trusted AI technologies that operate the platform and leverage all available resources to meet user requests reliably, efficiently, and optimally, directly benefiting the user of the service. AI-based tools for automatic validation, explanation, and correction of data-analytics models make the outcome more trusted from its origin. Besides providing a reliable privately secured environment for the users, the system creates additional support systems to guarantee upon request the auditability and explanation of the service, improving the overall level of trust between users and granting a higher degree of autonomy to the service provider. The creation of artificially intelligent digital brokers and assistants supported by Blockchain Technology that have the ability to monitor independently the user interests and effectively organize the offered services completes the high level of automation and independence on the commercial side.

Self-governing data ecosystems are empowered by the recent developments of privacy-enhancing computation technologies. A combination of different privacy-enhancing technologies (PET)—secure multiparty computation (MPC), federated learning (FL), homomorphic encryption (HE), differential privacy (DP), secret sharing (SS)—complements each other's weaknesses in such a way that their integration allows to perform a large number of data-analytics operations with strong privacy- confidentiality-assurance guarantees and no single trusted party in charge of the data. Data ecosystems where these privacy-enhancing techniques are empowered by compliance-by-design technologies express the capability of running operations in strict accordance with the regulations.

10.3.1. AI-Driven Orchestration and Decision Making

Several aspects of the orchestration and decision-making functionalities of an Autonomous Data Platform can benefit from AI-based technologies. The possibility of employing natural language interfaces for interacting with data ecosystems is motivating a new set of conversational systems capable of carrying a dialog with users and performing visual question answering over structured data. Such interfaces enable adequate abstraction and simplify the involvement of non-technical users in decision-making processes. Furthermore, leveraging the ontology of the data ecosystem to transform the knowledge into an interpretable graph enhances automatic visual query generation and selection. Although this represents only a small part of the workload

management task, it illustrates how the inclusion of LLMs helps achieve the objective of a simpler end-user interaction with a sufficient level of autonomy.

Data orchestration and decision-making capabilities are closely linked to the simulation and optimization of service deployments, enabling higher SLA fulfilment rates at lower costs by applying extensive yet tractable workloads using either off-line scheduling or real-time scaling. The adoption of neural-based models can enhance these capabilities, enabling adaptive workload management and evolving multiple objectives simultaneously. Neural decision engine-based deployment marketplaces can also evolve towards multi-agent coordination systems that allocate resources based on service/component demand, utility, and SLA estimation, while detection-origin neural prediction methods can help manage data pipelines in complex scenarios.

10.3.2. Privacy-Enhancing Computation and Compliance by Design

The increasing number of independently operating data ecosystems driven by autonomous systems and intelligent agents, each gathering and processing significant amounts of sensitive data, necessitates a paradigm shift in privacy processes. Data breach and misuse risks can be mitigated using privacy-preserving computation methods.

Fig 10.3: Privacy-Enhancing Computation and Compliance by Design

These enable parties to gain insight from shared data without revealing sensitive information to others, and most importantly, without requiring parties to rely on the trustworthiness of other parties or on a centralized trusted authority. Besides privacy-preserving technologies, autonomous and self-governing data platforms can employ compliance-by-design mechanisms that leverage an active compliance and security monitoring lifecycle, covering pre- and post-deployment phases. This is essential not

only for ensuring adherence to data-related legislation and regulations but also for providing a proactive assurance regarding the quality and security of shared data.

10.4. Challenges and Risk Management

Constructing autonomous and self-governing data platforms (ADPs and SGP-Dev) raises specific challenges that require thoughtful consideration and design-adjustment. The inherent risk of decentralization—loss of controllability—requires careful mechanisms, mechanisms that are different yet complementarily aligned within the ADP-process-architecture set. The following sub-sections identify representative challenge areas, articulate their implications on SGP-Dev and ADP processing, and identify risk categories corresponding to defined OS device frameworks and typical operations. A forward-looking assessment considers contemporary capabilities and seeks to elucidate the gap to fulfilling SGP-Dev and ADP aspirations.

Accountability, auditability, and explainability are dynamics that should accompany the self-governing data-ecosystem principle: key agents (data subjects, data providers, data controllers, etc.) must have enough understanding of the governing mechanisms to retain confidence in their purported misalignment-resisting behaviour. SGP-Dev processes should support formal mechanisms to (a) explain why a certain choice was made in a certain context for a certain operation, (b) assess whether the choice was in line with minimum principles (in-line with finality) and formal policies, and (c) audit the assumption and behaviour of agent FFs, either post-facto or on-range. Missing these can entail high risk, e.g., a too generous policy in a privacy-preserving query system, or a flaw in its FF mechanism, may lead either to data-leak question/answer pairs or an inflated answer-size budget wasted in vain. Similar capabilities in ADPs depend on two distinct considerations—explainable AI and orchestration.

10.4.1. Accountability, Auditability, and Explainability

The use of AI and ML for the orchestration and decision-making in data platforms raises novel accountability concerns, as traditional governance models may not scale or serve their purpose properly. The solutions to ensure appropriate auditability also show significant dependency on the underlying technology: A Deep Neural Network (DNN) model can instead solve challenges more natively than a Gradient Boosting Machine (GBM) without addition of ad hoc support due to their nature. Solutions such as neural dispropositionality ensure that DNNs, which work using constant neural excitation and rely on excessive correlation and co-correlation, do not become blind to alternatives or other paths. Moreover, as service-oriented platforms have historically had converged systems of monitoring and usage, there is expectation-put to meet service-level

agreements and to be technically supported with guarantee of minimum and maximum performance.

Simultaneously, explainability has become a recognised requirement by the market. Entities consuming machine decision preparation as a service and in third-party operating data environments demand being informed about the margin of error and requests for minimisation of negative consequences, to enable preparation for bad consequences or negative side effects specially. Expectations meeting these concerns are clearer in the financial market space, which has a long tradition of external audits of all business aspects. Just as yearly accounting audits became common practice, business demand for audit delegating of machine decision preparation is also expected at operational levels. Furthermore, although AI models have become used in diverse areas, more demand for understanding potentially negative decisions is raised than for positive decisions; clients desire to foresee actions to neutralise adverse consequences.

10.4.2. Security, Reliability, and Fault Tolerance

Self-governing data ecosystems effectively manage the accountability and auditability of data sharing and data use decisions, but AI-automated orchestration, operations, and support decisions can introduce new forms of risks, which in turn necessitate dedicated functionalities for security, reliability, and fault tolerance.

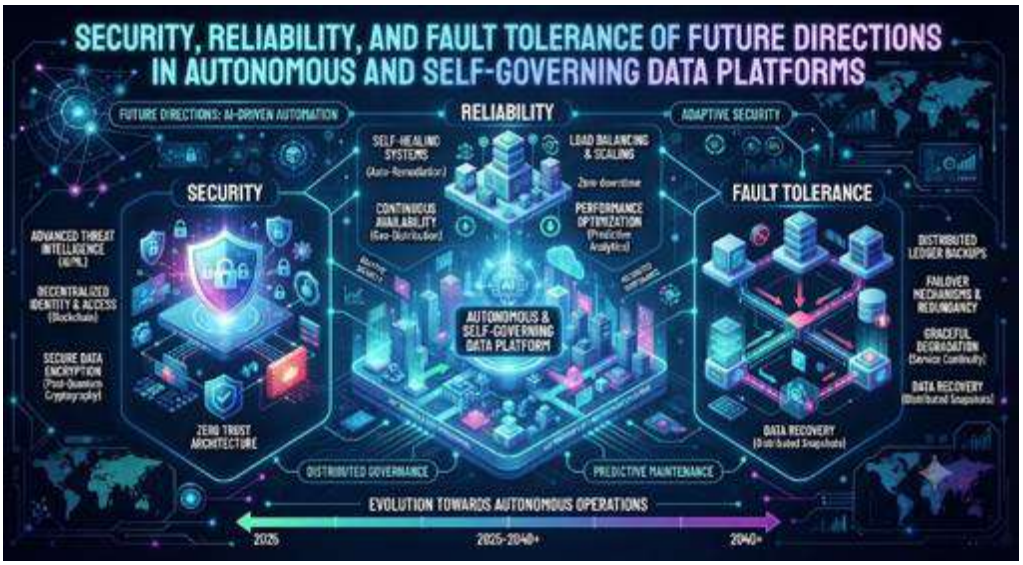

Fig 10.4: Security, Reliability, and Fault Tolerance

Deliberate and determined adversaries actively attempt to breach systems hosting sensitive data. Security is the property that aims at preventing and detecting threats and

attacks against the systems and the information they store. A principled understanding of security policies and mechanisms, including zoning circuits, data classification schemes, risk assessment methodologies, etc., underpin the design, implementation, and maintenance of security in any information system or service. Privacy-preserving secure multi-party computation, zero-knowledge proofs, federated learning, and more generally the methods and protocols that aim at preserving the privacy of sensitive information, are also security mechanisms when applied in threat models capturing malicious actors aiming to breach the confidentiality of the participants.

10.5. Conclusion

The combination of AI and data platforms continues to attract an abundance of attention, which has heightened interest in enabling technologies such as reinforcement learning, deep learning, formal verification, and privacy-preserving machine learning and computation techniques. Developments from business and product perspectives have also spawned research into autonomous platforms in specific environments, such as healthcare or finance. Nevertheless, a large gap remains in addressing the foundational architectural principles, enabling technologies, characterizing risk, and assessing auditability and transparency—topics that will allow for a broader debate on the governing autonomization.

Visualizing the above-described architectural principles and autonomous governance mechanisms as a strawman is thus crucial. Risk remains a major concern, especially in critical scenarios involving autonomous agents. The assurance of auditability, accountability, reliability, availability, security, and fault tolerance should therefore be the first topic in any practical introduction to autonomous data platforms. Ultimately, risk management and the analysis and design of the workspace must ramp to the same depth as the enabling technologies of AI for autonomous decision-making and orchestration as well as privacy-preserving computation for both privacy-enhancing and compliance-by-design paradigms, currently active in the general area of enabling technology for data platforms and ecosystems.

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