Section 1: Week 2: Organizational Data Management Problems

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EdTech Data Management

Educational institutions need to maintain student rostering information, such as the class enrollments and the instructional hierarchy of their courses. In some instances, these institutions must associate their rosters with parent organizations, such as county and state districts. Specific aspects of these hierarchical structures are made available to various third-party providers that use these feeds to expose an ecosystem of personalized student learning, teacher dashboarding, and classroom analytical tooling.

# Challenges of Data Sharing

Innovating within the Education Technology (EdTech) ecosystem is challenging because of non-uniform exchange protocols, insufficient information governance, and inefficient synchronization strategies. These issues complicate data management solutions and force businesses to design solutions that operate in a heterogeneous environment that cannot adequately address the needs of its audience.

## Use of Proprietary Protocols

Student enrollments are not static, and mechanisms need to exist for notifying partners of these changes. These notifications started life as proprietary unstructured messages that lacked a focus on interoperability (IMS, 2019). The Instructional Management Solutions (IMS), an international standards organization, has proposed OneRoster to standardize the communication protocol. However, these efforts need broader adoption by the tool ecosystem and more strict enforcement of data values. Many schools degrade the contract to semi-structured messages because they lack sophisticated data quality processes (Herald, 2016). Herald provides an example that different systems might know the same student as Jim, Jimmy, and James. Another challenge arises from the reuse of student numbers (primary key) that might be unique within a given school (local context) but overlap at the district level (global context).

## Insufficient Privacy and Security Controls

Parents, administrators, and legislatures have concerns regarding the privacy of student information (Regan & Jesse, 2019). Regan and Jesse state that federal regulators oversee sharing between organizations using powers granted under the Family Educational Rights and Privacy Act of 1974 (FERPA), Children’s Online Privacy Protection Act of 1998 (COPPA), and related laws. “The central tension in Edtech is between the need to protect student data privacy on the one hand, and Edtech companies’ ability to innovate on the other (Peterson, 2016, p. 962).” Peterson’s statement is missing the critical point that students have entrusted their data to their schools explicitly, and the EdTech implicitly. These additional protections necessitate an information governance policy that is natively part of the roster sync protocols, at both a coarse (e.g., entity filters) and fine-grained (e.g., attribute filters) level of control.

## Inefficient Synchronization Protocols

A third aspect of the problem is an inability to perform data integrity checks and efficiently remediate in real-time. Many third-party consumers handle this drift through a full periodic synchronization with the source of truth. However, this can be challenging to scale across large customer bases with millions of students. The delays also reduce the customer experience, as students cannot immediately enjoy the third-party products (ClassLink, 2018). Specific sources of truth providers expose proprietary protocols for streaming update deltas (Clever, 2019). These solutions introduce external system dependencies, such as Lightweight Directory Access Protocol (LDAP), that can be clunky for specific workloads.

# Evaluating Solutions

Similar to other brick and mortar establishments, school districts are slow to adopt change, and EdTech businesses need to find solutions that minimize these data management constraints. These solutions need to (1) leverage data stores that align with the schema and access patterns, (2) promote security and privacy, and (3) replicate across partially trusted disjoined organizations.

## Data Store Selection

There are several different Storage as a Service (StaaS) solutions available to host the student data, each with a unique workload optimization point (Mansouri, Nadjaran, & Buyya, 2017). Due to a lack of schema standardization between organizations, a NoSQL store would be more appropriate than a traditional Relational store. In a relational system, such as Postgres or Microsoft SQL Server, they rely on ‘schema on write’ protocols, which would work for a subset of organizations (Zambetti, Pinto, & Pezzotta, 2019). Instead, key-value and document stores can accept the opaque third-party payloads and leverage ‘schema on reading’ strategies at a later stage in the pipeline.

Different abstraction layers exist across NoSQL stores for simplification of data modeling and access patterns. If the business questions start from *known* entities*,* then a graph database might be the right choice (Kronmueller, Chang, Hu, & and Desoky, 2018). However, a more exploratory system that begins from *unknown* objects might select an in-memory store instead (Knabke & Olbrich, 2018). Consider the difference between (a) find all students in Ms. Allen’s math class and (b) all third-grader girls with a low grade in history. **Scenario (a)** begins at Ms. Allen (vertex) and then traverses associations (edges) to her students (vertices). While a relational store would need to use globalized table indexes, a graph database can efficiently use indexes local to the vertex to find the related objects (Patil, Kiran, Kavya, & Naresh, 2018). These optimizations enable the system to scale to higher degrees of complexity and more massive data sets. However, these local indexes can introduce additional costs when the starting point is unknown and needing to consider many teachers (initial vertices). **Scenario (b)** addresses these challenges by reversing the index and mapping keyword terms to document identifiers. Then, the query *all third-grade girls* can decompose into the statement term\_lookup(‘gender: female’) UNION term\_lookup(‘grade: 3’). Each resulting primary-key can be retrieved directly from the store.

## Information Governance

Administrators, parents, and students expect their data remains private and secure on third-party systems. These assurances require information governance policies that focus on security and access control (Taleb et al., 2018) (McKendrick, 2019). Taleb et al. propose process-driven strategies that clean incoming data and remove sensitive details. Consider the scenario where XYZ school includes student email and physical addresses in their roster. If ABC EdTech does not support physical mail, then those attributes should be truncated. Governance should also consider data retention periods and remove data that is no longer needed, to further reduce the attack surface.

McKendrick expands on these ideas by demarcating the technology stack into a Data Lake and Data Warehouse. He proposes leaving the source data inside of the Data Lake and then constructing Extract Transform and Load (ETL) workflows to move normalized structure into an Online Analytical Processing (OLAP) Data Warehouse. Afterward, industry-standard patterns exist for employing explicit row and column level security across OLAP technologies (Amazon, 2019) (Microsoft, 2019) (Oracle, 2017).

While McKendrick’s strategy provides a clear separation of *internal* and *external* data, it trades explicit security decisions for an increase in complexity. Exposing new attributes through the OLAP system requires changes to multiple aspects of the data pipeline. It can be problematic to scale the access management policy as the (a) number of partners and (b) the level of granularity increases. Another critical concern is this approach requires moving to a relational model that does not align with the business use cases. Instead, a security solution needs to exist across the NoSQL store directly.

Network administrators on the Amazon Web Service (AWS) cloud can configure such a model using DynamoDB and IAM Security Roles for similar document and attribute level protections (Amazon, 2019). Microsoft Azure offers the same experience through its CosmoDB and DocumentDb products. Both Public Cloud Solution Providers (CSP) also have integrated solutions for encryption and access auditing.

## Heterogeneous Replication

An interesting problem exists with the need to keep partially trusted disjoined organizations in sync across various technology stacks. When a remote replica is missing a segment of student data, then those students are impaired and unaccounted in reporting platforms. The naïve solution is to perform a full synchronization on a configured cadence. However, for specific scenarios, such as freemium models, these discrepancies cause unacceptable delays to the business model (Eaton, 2012).

An alternative mechanism could pull data during a lifecycle event, such as when a user authenticates into the system (Freckle, 2019). This approach can lead to questions from administrators regarding ‘why aggregate entity counts are inconsistent and fluctuate across the school year.’ A more efficient strategy can send push notifications between the systems when a change has occurred. These announcements across hierarchical structures should align and account for the natural branch structure (Kvet & Matiasko, 2019). For example, when a student enrolls in a course, then subscribers should receive notifications for that object in addition to the parent objects (e.g., school). This strategy allows for third-parties to register for events at the level of granularity that is relevant to their product. The message to the receiver should contain object pointers, instead of the value directly to conserve network resources between organizations (Steen & Tanenbaum, 2016).

An assumption with notification strategies is the subscriber is highly-available and highly-reliable. If (a) an extended outage occurs or (b) an event that resulted in data corruption, then the two organizations will be out of sync. After restoring to an arbitrary point in time, a process needs to verify each segment of the local replicas is consistent. A novel management strategy could rely on Merkle trees to provide checksums over the hierarchical rostering data, similar to solutions found in peer-to-peer networks (Kan & Kim, 2019) (Furtado, 2005). For instance, the validation checksum for a school equals hash(hash(courses)), with the hash(course) equal to hash(hash(associated users)). These validation trees could be maintained by the source of truth stores while encountering minimal protocol overhead, and are small enough to scale across enormous datasets. Third-party systems could reference these validation trees for fine-grained detection of errors.

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