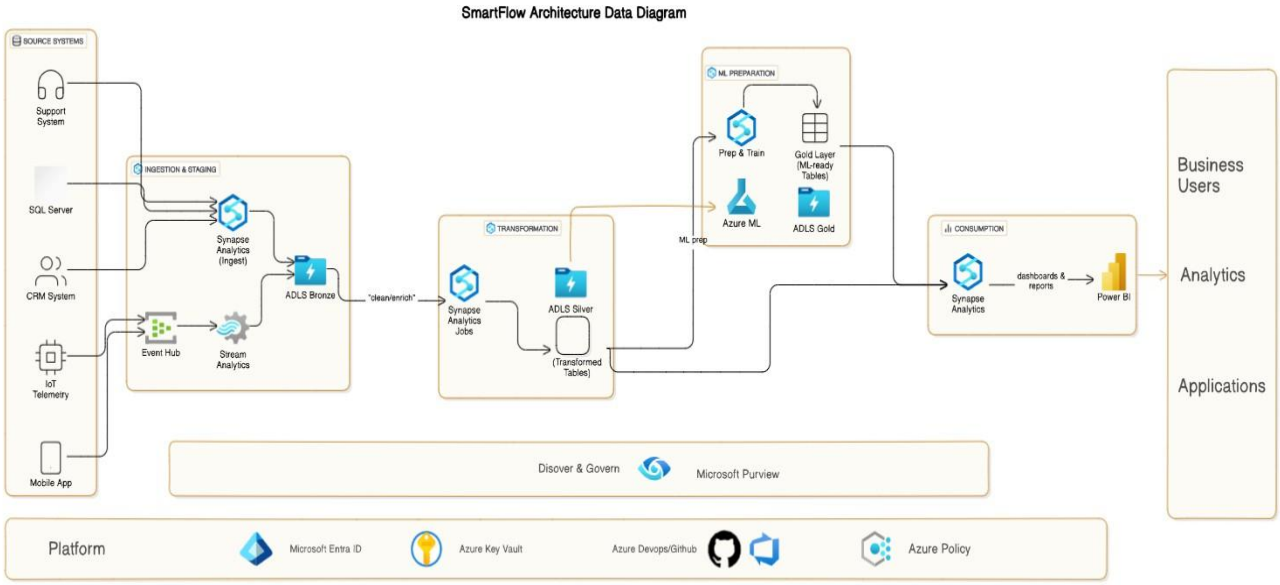
# SmartFlow Data Architecture,

# Modeling, Governance, and ML/AI Serving Documentation

1. Architecture Diagram:




# 1. Data Flow & Medallion Architecture

### 1.1 Overview

SmartFlow ingests data from heterogeneous source systems—including CRM, SQL Server OLTP, IoT telemetry devices, mobile applications, and support systems—via both batch and streaming pipelines. All raw data lands in a **Bronze** zone for durability and replay, progresses to **Silver** where it is cleansed and conformed, and culminates in **Gold** tables optimized for analytics, reporting, and ML workloads. Microsoft Purview provides end-to-end discovery and lineage, while platform services such as Azure Key Vault and Azure Policy enforce security and guardrails.

### 1.2 Batch Ingestion Path

1. **Source Extraction**: Nightly or hourly extracts from SQL Server and CRM via Synapse Analytics pipelines ( i.e Copy Data).

2. **Landing (Bronze)**: Data is written raw into an Azure Data Lake Storage (ADLS) container in a bronze/ folder, partitioned by ingestion date (YYYY/MM/DD).
3. **Transformation to Silver**: Azure Synapse Spark jobs run ELT notebooks to:
    - Deduplicate and normalize business keys
    - Parse, type-cast, and enrich with reference lookups
    - Write cleaned tables to silver/ folder, partitioned by business date and region
4. **Promotion to Gold**: Scheduled Synapse SQL pipelines aggregate and join multiple silver tables into curated gold models.

**1.3 Streaming Ingestion Path**

1. **Event Hub → Stream Analytics**: IoT and mobile events stream into Azure Event Hubs. Azure Stream Analytics jobs perform lightweight filtering and windowed aggregations, writing output to Bronze.
2. **Bronze → Silver**: Synapse Streaming Spark jobs continuously read bronze folders (or via Azure Synapse pipelines' Delta Autoloader) to:
    - Enrich with master data
    - Apply business rules (e.g., anomaly detection)
    - Write to silver/telemetry/ as micro-batch Delta tables
3. **Real-Time Gold**: Low-latency Synapse SQL on-demand queries produce real-time views in Gold, backed by materialized views for dashboards.

**1.4 Medallion Layers Summary**

| Layer | Purpose | Storage Location | Partitioning | Consumers |
|---|---|---|---|---|
| Bronze | Raw, immutable snapshots | adls://.../bronze/ | ingest_date=YYYY/MM/DD | Data engineers |
| Silver | Cleaned, conformed, enriched datasets | adls://.../silver/ | business_date=YYYY-MM-DD/region=XX | BI developers, data scientists |
| Gold | Aggregated, highly curated analytics tables | adls://.../gold/ | Varies by subject area (date, custID) | Power BI, ML models, APIs |

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# 2. Data Modeling Document

**2.1 Key Models for Silver & Gold**

- **Silver**: 1) **Customer_Events_Silver**; 2) **Transaction_Facts_Silver**; 3) **Device_Telemetry_Silver**

- **Gold**: 1) **Customer360_View**; 2) **Daily_Revenue**; 3) **AnomalyAlerts_View**

**2.2 Entity Definitions**

**2.2.1 Customer (Silver)**

| Column | Type | Description | Partition Key | Sort/Cluster |
|---|---|---|---|---|
| customer_id | STRING | Surrogate key | | |
| source_customer_id | STRING | Original ID from CRM | | |
| name | STRING | Full name | | |
| email | STRING | Email address | | |
| signup_date | DATE | Date of first registration | business_date | |
| region | STRING | Geographic region | | |

**Partitioning**: by signup_date (YYYY-MM) to support time-based lookups.
**Optimization**: Use Z-ordering on region for skewed regional queries.

**2.2.2 Transaction (Silver)**

| Column | Type | Description | Partition Key | Sort/Cluster |
|---|---|---|---|---|
| transaction_id | STRING | GUID | | |
| customer_id | STRING | FK to Customer | | |
| product_id | STRING | FK to product catalog | | |
| amount | DECIMAL(10,2) | Transaction value | | |
| transaction_date | TIMESTAMP | Event timestamp | business_date | |
| payment_method | STRING | E.g., CreditCard, PayPal | | |

**Partitioning**: by business_date (daily) for efficient retention.
**Optimization**: Cluster by customer_id and Z-order on transaction_date.

**2.2.3 Device Telemetry (Silver)**

| Column | Type | Description | Partition Key | Sort/Cluster |
|---|---|---|---|---|
| device_id | STRING | Unique device identifier | | |
| event_time | TIMESTAMP | Telemetry timestamp | event_date | |
| metric_type | STRING | E.g., temperature, vibration | | |
| metric_value | DOUBLE | Measured value | | |

| | | |
|---|---|---|
| region | STRING | Physical deployment region |

**Partitioning**: by event_date (daily) to support time series retention.
**Optimization**: Use data compaction and Delta auto-optimize enabled.

**2.3 Gold Layer Models & Optimization**

**2.3.1 Customer360_View (Gold)**

- Joins Customer (silver) + aggregate metrics from Transaction and Telemetry
- Partition on region, year_month (YYYY-MM)
- Indexing: create materialized view in Synapse providing precomputed KPIs per customer-month.

**2.3.2 Daily_Revenue (Gold)**

- Pre-aggregated daily revenue by product and region
- Partition by report_date
- Use Synapse dedicated SQL pool clustered columnstore tables for large fact scans.

**2.3.3 AnomalyAlerts_View (Gold)**

- Real-time view combining latest telemetry anomalies with business rules
- Maintain as an external table over Delta streaming sink with granularity of 5-minute windows

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# 3. Data Governance Strategy

**3.1 Data Quality & Lineage**

- **Quality Rules**: Implement Delta Expectations in Silver tables—uniqueness, not-null, range checks.
- **Automated Validation**: Azure Data Factory Data Flow Assertions, Pyspark Great Expectations integration.
- **Lineage Tracking**: Microsoft Purview scans ADLS and Synapse metadata to generate a graph of lineage from raw ingestion to Gold datasets.

**3.2 Metadata Management**

- **Glossary & Catalog**: Define business terms (e.g., "Customer Lifetime Value") in Purview.
- **Tagging**: Tag all tables/columns with classification labels (PII, Confidential, Public).

**3.3 Sensitive Data Controls**

- **Discovery & Classification**: Purview automated scanners to detect PII in Bronze and Silver.

- **Access Policies**: Azure RBAC combined with Synapse workspace roles to restrict access to PII classified tables.
- **Encryption**: All data encrypted at rest (ADLS SSE with Microsoft-managed keys or BYOK in Key Vault) and in transit (TLS).

**3.4 Monitoring & Alerting**

- **Pipeline Health**: Azure Monitor alerts on ADF/Synapse pipeline failures, latency SLAs breaches.
- **Data Freshness**: Custom Log Analytics queries to detect missing partitions or late arrivals, with email or Teams notifications.
- **Quality Metrics**: Push Delta Expectation results to Azure Metrics and trigger alerts when thresholds exceeded.

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# 4. ML/AI Data Serving Strategy

**4.1 Data Preparation for Modeling**

- **Feature Generation**: Use Spark on Silver to compute rolling metrics, aggregations, and one-hot encodings.
- **Gold Layer for ML**: Create a dedicated set of tables in Gold (e.g., ml_features.gold_customer_features) stored in Delta, partitioned by snapshot_date.
- **Unstructured Data Handling**: Store raw documents or logs in bronze/unstructured/, process via synapse notebooks into embeddings stored in Delta or Cosmos DB.

**4.2 Feature Store Requirements**

- **Centralized Feature Store**: Deploy Azure ML Feature Store preview to register, share, and serve features.
- **Online & Offline Stores**:
    - **Offline**: Delta tables in ADLS for batch training.
    - **Online**: Azure Cosmos DB or Redis for low-latency feature lookups in production inference.
- **Versioning**: Feature version metadata maintained in the store to ensure reproducibility.

**4.3 Serving to Models**

- **Batch Training**: Orchestrate Azure ML pipelines that read offline features and unstructured embeddings, train models, and log metrics back to MLflow.
- **Real-Time Inference**:
    - Functions in Azure Functions or FastAPI deployed to AKS call online feature store and serve predictions.

- Data freshness managed via incremental streaming Delta writes and Event Grid notifications.

**4.4 Structured & Unstructured Integration**

- **Structured**: Ingest via Silver → transform to Gold features → register in Feature Store.
- **Unstructured**: Use Databricks MLFlow pipelines to extract text embeddings or image features, store embedding vectors in a Delta table.
- **Model Training**: Combine structured features join with embeddings on customer_id or device_id for end-to-end training.