

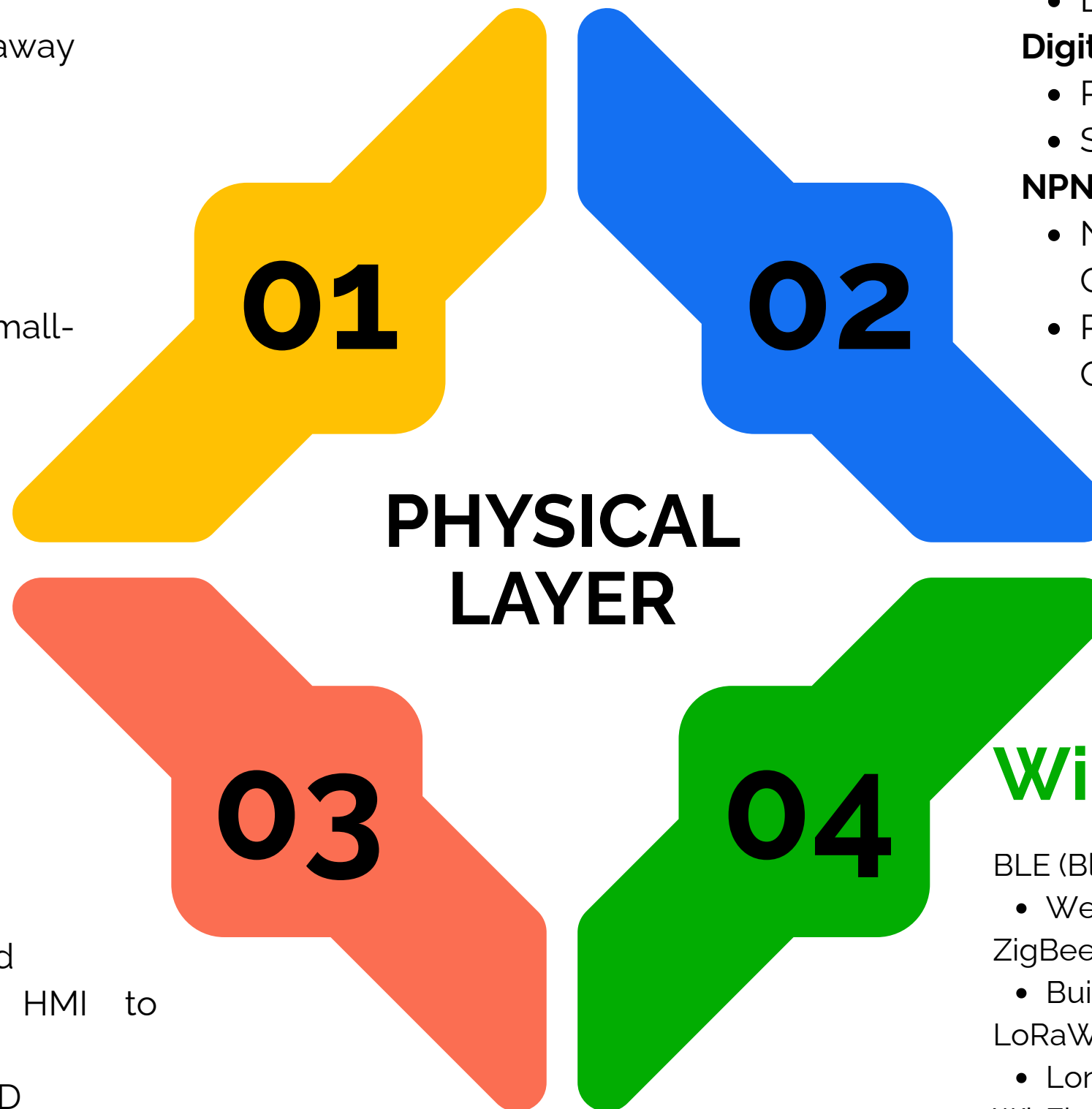
Analog Signals

4-20mA Current Loop

- 2-wire loop, 24VDC supply
- Good for long runs, noise immunity
- Example: chemical storage tank far away from control room

0-10V Voltage Signal

- 3-wire (V+, GND, Signal)
- Low cost, easy to implement
- Short runs only, susceptible to EMI
- Example: Building automation, small-scale machinery



Digital I/O

Digital Inputs

- 24V=ON/0V=OFF
- Limit/Prox Switches, Photoeye/Pushbuttons

Digital Outputs

- PLC controlled
- Solenoids/Contactors/Indicator lights

NPN vs PNP

- NPN (sinking): Sensor pulls input when ON. Common in Asia.
- PNP (sourcing): Sensor provides input when ON. Common in NA/Europe.

Serial Comms

RS-232

- Point-to-point, ~15m max cable, low speed
- Programming legacy devices, single HMI to controller
- Example: Laptop plugged directly into VFD

RS-485

- Multi-drop bus, up to 1200m run
- Connects multiple instruments to one PLC
- Terminate both ends with resistors

Wireless

BLE (Bluetooth Low Energy)

- Wearables for worker safety

ZigBee

- Building automation (lighting, HVAC thermostats)

LoRaWAN

- Long range, low power sensors for environmental monitoring

Wi-Fi

- HMIs and tablets, cameras and data loggers

NB-IoT/LTE-M

- Remote assets where no local network exists

5G

- AGVs (Automated Guided Vehicles)

PLC

Use

- Discrete control, sequencing, interlocks, safety

Cycle time

- 1-20ms/scan

Language

- Ladder, Function Block, Structured Text, Sequential Function Chart

Vendors

- Rockwell (Allen Bradley), Siemens, Schneider, Mitsubishi, Omron

CNC

Use

- Machine tools (mills, lathes, laser cutters)

Cycle time

- <1ms loops

Language

- G-code, M-Code, Parametric, STEP-NC

Vendors

- FANUC, Siemens Sinumerik, Haas, Heidenhain

DCS

Use

- Continuous process control

Cycle time

- 100-500ms loops

Language

- Function Block Diagrams, Sequential Function Charts, Structured Text

Vendors

- Honeywell Experion, Emerson DeltaV, Yokogawa Centum, ABB System 800xA

Robots

Use

- Welding, painting, pick-and-place, palletizing, assembly

Cycle time

- 1-4ms servo updates

Language

- KAREL, RAPID, KRL, INFORM, URScript

Vendors

- FANUC, KUKA, ABB, Yaskawa, UR



**CONTROL
LAYER**

Modbus

RTU (RS-485)

- Serial, master/slave polling, twisted pair, up to 32 devices/bus. 9600-115200 bps.

TCP (Ethernet variant)

- Easier to integrate into IT networks, supports more nodes

Use

- Simple device integration, wide supported across meters, sensors, drives

Example

- PLC polls power meter via Modbus RTU to log energy consumption

Profinet

NRT (Non Real Time)

- Runs on standard TCP/IP, diagnostics, configuration, file transfers

RT (Real Time)

- Bypasses TCP/IP for faster I/O exchange. Cycle time 1ms for standard I/O and control applications

IRT (Isochronous Real Time)

- Adds time slot + IEEE-1588 PTP synchronization. <1ms update times. Synchronized multi axis motion.

Topology

- Star, line, or ring.

Use

- High speed automation, drives, motion systems, large distributed I/O networks

Example

- High speed packaging machines uses Profinet IRT to synchronize multiple servo drives for coordinated, millisecond level motion

Profibus

DP (Discrete Peripherals)

- RS485 fieldbus for PLC <-> I/O communication. Cyclic master/slave exchanges. Widely used in discrete manufacturing. 12Mbps.

PA (Process Automation)

- Runs on MBP physical layer, designed for hazardous/explosive environments. Power + comms over same 2-wire bus.

Use

- Reliable communication with field devices, popular in Europe for both factory and process automation

Example

- Chemical plant uses Profibus PA to connect sensors in explosion-proof zone to control system

Ethernet/IP

CIP (Common Industrial Protocol)

- Object oriented architecture used across different transport layers: Devicenet, Controlnet, Ethernet/IP, Componet

Explicit Messaging (TCP)

- Request/response,for configuration, diagnostics, and less time critical data

Implicit Messaging (UDP)

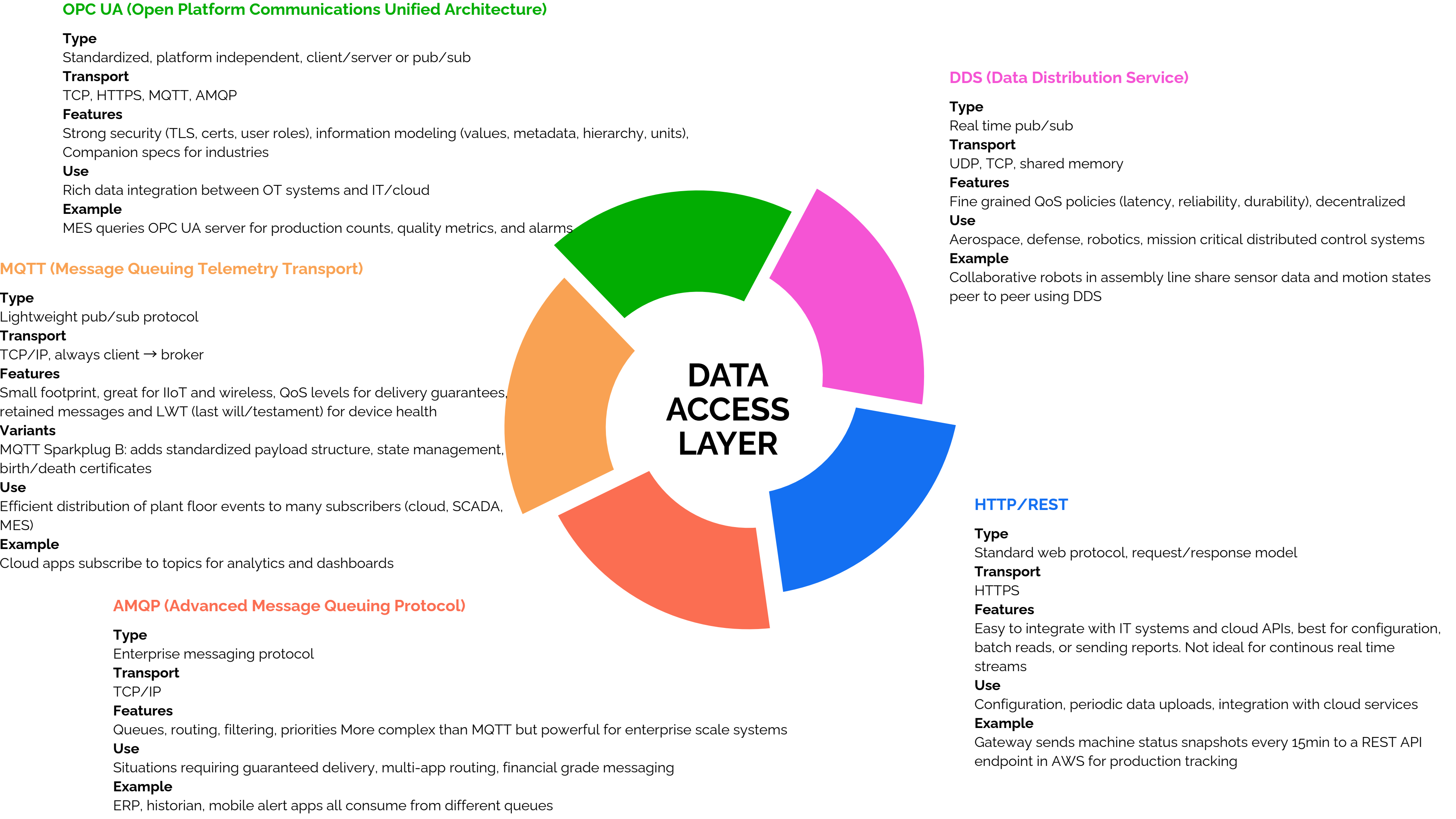
- Real time, cyclic I/O data exchange between controllers and devices

Use

- Popular in North America, distributed I/O, drives, robots, PLC to PLC links

Example

- Rockwell PLC controls distributed I/O racks and VFDs over Ethernet/IP



GATEWAYS

01

Protocol Translation

Southbound (OT): Modbus RTU/TCP, Profinet, Ethernet/IP, BACnet, Profibus

Northbound (IT): OPC UA, MQTT, HTTPS, AMQP, DDS

02

Data Aggregation

Collects signals from multiple devices (PLC1, PLC2, Robot) and packages them into one data model

03

Normalization, Filtering, Buffering

- Converts raw tags into standardized units.
- Local rules: only send changed values, filter noise, signal compression.
- Buffer during WAN outage, forward once reconnected

04

Security Boundary

- Terminate TLS/mTLS connections.
- Act as firewall/DMZ between IT and OT. Identity management

05

Edge Processing

- Run ML inference models, detect anomalies, trigger alarms.
- Pre-aggregate KPIs before sending

ENTERPRISE / CLOUD LAYER

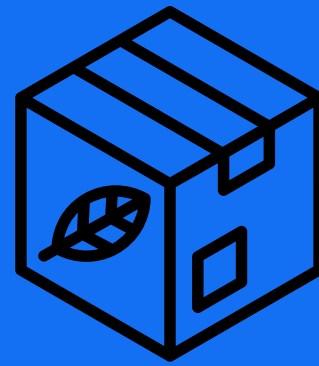


Ingestion

OT data gets ingested into the cloud system

MQTT, REST, Kafka/Event Hubs bring data in

01



Storage

Where data lands and how it's organized

- Hot: real-time, short-term (TSDB)
- Warm: operational, medium-term (RDS)
- Cold: historical, long-term (Data Lake)

02



Processing

Raw data is transformed, enriched, and analyzed

Stream (real-time), batch (ETL), ML/AI models

03

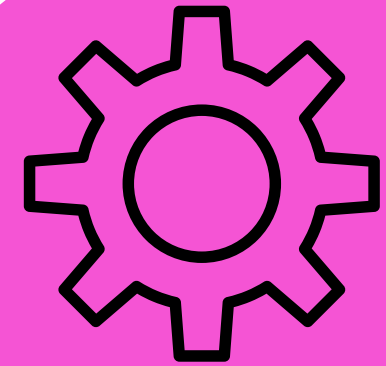


Serving

Data is consumed for business value

Dashboards, MES/ERP, APIs, alerts

04



Governance

Rules and infrastructure to ensure trust and compliance

Security, schemas, compliance, observability

05