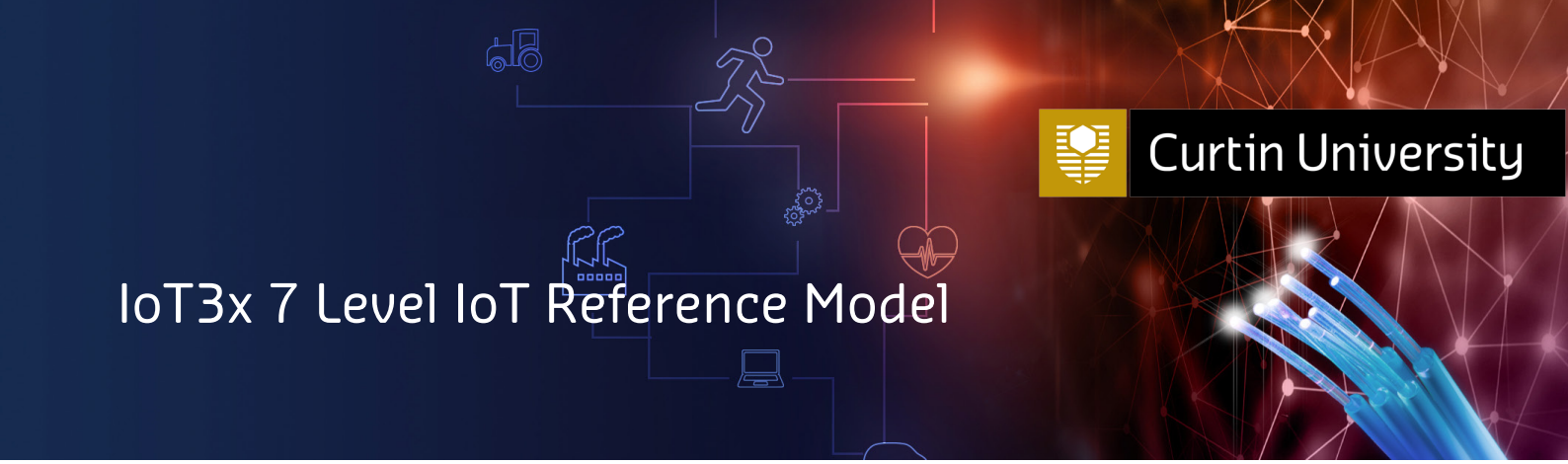


7 Level IoT Reference Model

Level 1: Physical Devices and Controllers

This layer comprises a wide range of endpoint devices that send and receive information and the physical devices and controllers that control them.

The IoT must support all these devices which can be a diverse range of size, location, form factor, or origin.

These IoT "devices" are capable of:

- Analog to digital conversion, as required
- Generating data
- Being queried / controlled over-the-net

Level 2: Connectivity

Communications and connectivity are concentrated in Level 2.

The most important function of this level is reliable, timely information transmission.

This includes transmissions:

- Between devices (Level 1) and the network
- Across networks (east - west)
- Between the network (Level 2) and low - level information processing occurring at Level 3

Level 1 devices communicate through the IoT system by interacting with Level 2 connectivity equipment.

Connectivity includes:

- Communicating with and between the Level 1 devices
- Reliable delivery across the network(s)
- Implementation of various protocols
- Switching and routing
- Translation between protocols
- Security at the network level
- (Self-Learning) Networking Analytics

The IoT should not require a different network—it relies on existing networks.

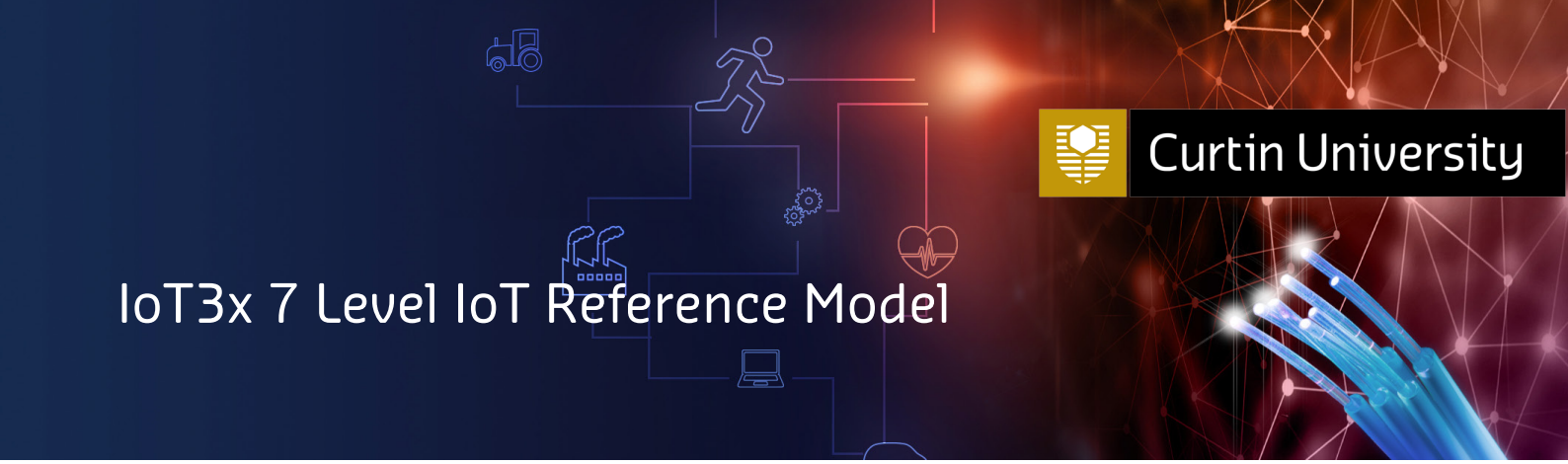
Until complete standardisation is achieved some legacy devices which are not IP-enabled will require communication gateways; and others may require proprietary controllers to serve the communication function.

Level 3: Edge (Fog) Computing

The functions of Level 3 are driven by the need to convert network data flows into information that is suitable for storage and higher-level processing at Level 4 (data accumulation).

Level 3 activities focus on high-volume data analysis and transformation.

For example, a Level 1 sensor device might generate data samples multiple times per second, 24 hours a day, 365 days a year.



IoT3x 7 Level IoT Reference Model

A basic tenet of the IoT Reference Model is that the most intelligent system initiates information processing as early and as close to the edge of the network as possible.

This is sometimes referred to as fog computing and occurs at Level 3.

Given that data is usually submitted to the connectivity level (Level 2) networking equipment by devices in small units, Level 3 processing is performed on a packet-by-packet basis.

This processing is limited, because there is only awareness of data units —not “sessions” or “transactions.”

Level 3 data element functions include:

- Data filtering, clean up, aggregation
- Packet content inspection
- Combination of network and data level analytics
- Thresholding
- Event generation

Level 3 processing examples include:

- Evaluation: Evaluating data for criteria as to whether it should be processed at a higher level
- Formatting: Reformatting data for consistent higher-level processing
- Expanding/decoding: Handling cryptic data with additional context (such as the origin)

- Distillation/reduction: Reducing and/or summarizing data to minimize the impact of data and traffic on the network and higher-level processing systems
- Assessment: Determining whether data represents a threshold or alert; this could include redirecting data to additional destinations

Level 4: Data Accumulation

Level 4 provides the mechanisms to make network data usable by applications.

This level:

1. Converts data-in-motion to data-at-rest
2. Converts format from network packets to database relational tables
3. Achieves transition from 'Event based' to 'Query based' computing
4. Reduces data through filtering and selective storing

Level 4 is the boundary between event-based data generation and upper level query-based data use.

Networking systems reliably move data; the data is "in motion".

Up to Level 4, data is moving through the network at the rate and organization determined by the devices generating the data, meaning that actions are event driven.

However, most applications cannot, or do not need to, process data at network speed.

Applications typically assume that data is "at rest"—or unchanging—in memory or on disk.

Level 4 determines:

- If data is of interest to higher levels: If so, Level 4 processing is the first level that is configured to serve the specific needs of a higher level.
- If data must be persisted: Should data be kept on disk in a non-volatile state or accumulated in memory for short-term use?
- The type of storage needed: Does persistency require a file system, big data system, or relational database?
- If data is organized properly: Is the data appropriately organized for the required storage system?
- If data must be recombined or recomputed: Data might be combined, recomputed, or aggregated with previously stored information, some of which may have come from non-IoT sources.

As Level 4 captures data and puts it at rest, it is now usable by applications on a non-real-time basis when necessary.

Level 4 bridges the real-time networking world and the non-real-time application world.

Level 5: Data Abstraction

IoT systems will need to scale to a corporate—or even global—level which will require multiple storage systems to accommodate IoT device data and data from traditional enterprise non-IoT systems.

This requires Information Integration that:

1. Creates schemas and views of data in the manner that applications want
2. Combines data from multiple sources, simplifying the application
3. Filters, selects, projects, and reformats the data to serve the client applications
4. Reconciles differences in data shape, format, semantics, access protocol, and security

The data abstraction functions of Level 5 renders data and its storage into forms that enable the development of simpler, performance-enhanced applications.

With multiple devices generating data, the data may end up across dispersed storage. Reasons for this may include:

- There might be too much data to put in one place.
- Moving data into a database might consume too much processing power, so that retrieving it must be separated from the data generation process.
- Devices might be geographically separated, and processing is optimized locally.
- Levels 3 and 4 might separate “continuous streams of raw data” from “data that represents an event” so that each require different data processing applications.
- Different kinds of data processing might be required. For example, in-store

processing will focus on different things than across-all-stores summary processing.

The data abstraction level must therefore perform many different processes including:

- Reconciling multiple data formats from different sources
- Assuring consistent semantics of data across sources
- Confirming that data is complete to the higher-level application
- Consolidating data into one place or providing access to multiple data stores through data virtualization
- Protecting data with appropriate authentication and authorisation
- Normalising or de-normalising and indexing data to provide fast application access
- Data Abstraction (Aggregation & Access) Abstracting the data interface for applications

Level 6: Application

Level 6 is the application level, where information interpretation, reporting, and control occurs.

Software at this level interacts with Level 5 and data at rest, so it does not have to operate at network speeds.

Applications at this level vary based on vertical markets, the nature of device data, and

business needs.

Some examples of application focus include:

- Monitoring device data.
- Controlling devices
- Combining device and non-device data

The functional characteristics of the applications are determined by non-IoT software engineering and programming considerations.

Application examples include:

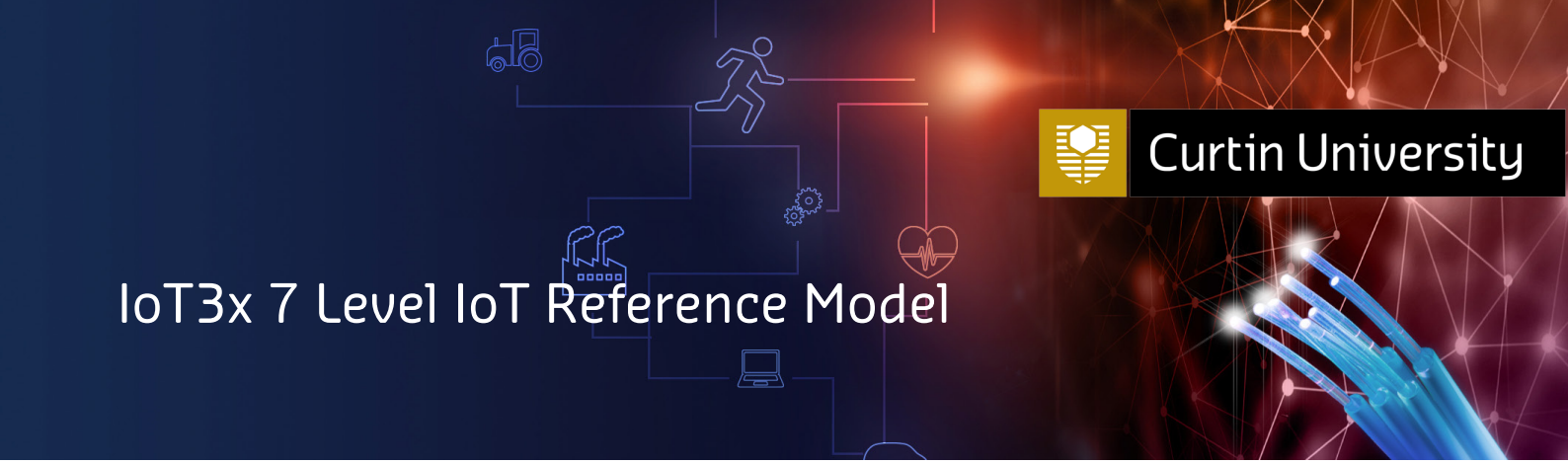
- Mission-critical business applications, such as generalized enterprise resource planning (ERP) or specialized industry solutions
- Mobile applications that handle simple interactions
- Business intelligence (BI) reports, where the application is the BI server
- System management/control centre applications that control the IoT system itself and do not act on the data produced by it

Level 7: Collaboration and Processes

Level 7 moves beyond the technical model and includes people and business processes

The IoT system, and the information it creates, is of little value unless it yields action, which often requires people and processes.

People use applications and associated data for their specific needs.



IoT3x 7 Level IoT Reference Model

Often, multiple people use the same application for a range of different purposes.

The objective is not the application, but to equip people to make better decisions and to take the appropriate actions.

Applications (Level 6) give business people the right data, at the right time, so they can do the right thing.

But frequently, the action needed requires more than one person.

People must be able to communicate and collaborate, sometimes using the traditional Internet, to make the IoT useful.

Communication and collaboration often requires multiple steps.

And it usually transcends multiple applications. This is why Level 7, represents a higher level than a single application.