industrial internet CONSORTIUM

Communications & Connectivity

Industrial Internet Innovation Forum

Dr. Rajive Joshi
Co-Chair, Connectivity Task Group, Industrial Internet Consortium (IIC)
Principal Solution Architect, Real-Time Innovations Inc (RTI)

2017 March 20
Thu, 15:00 EST
Reston, VA, USA

Agenda

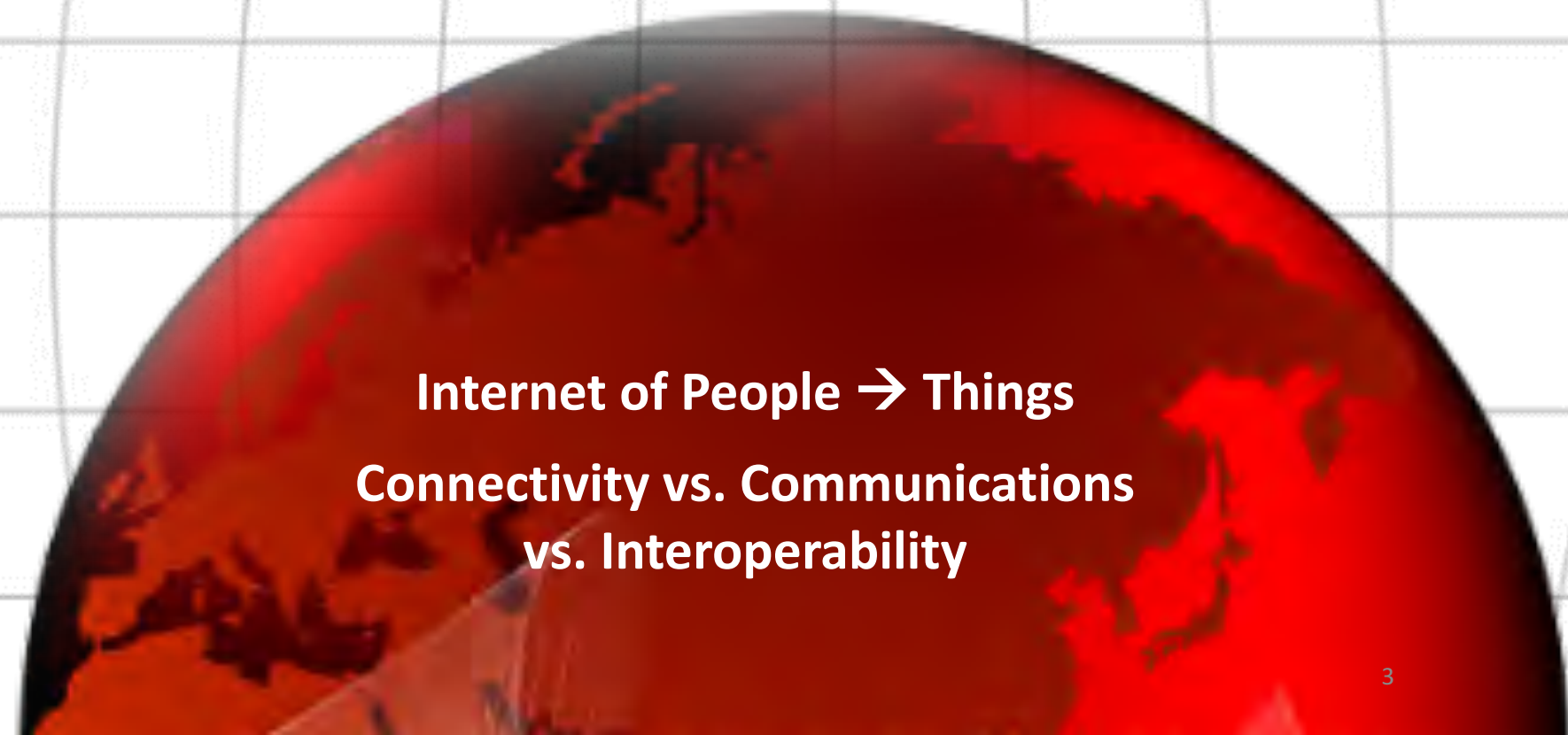
1. How do we go from here to there?
   - Internet of People → Things
   - Connectivity vs. Communications vs. Interoperability

2. Evolution of the IIoT connectivity stack
   - Connectivity Framework
   - Connectivity Transport

3. Defining a long term stable IIoT architecture strategy
   - Embracing the old and the new
   - Connectivity core standards criteria

4. Selecting the right connectivity technology
   - Assessment template worksheets
   - Connectivity standards

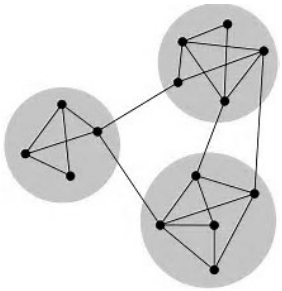
How do we go from here to there?



Internet of People → Things

Connectivity vs. Communications vs. Interoperability

How do we go from here to there?



?

People

Internet of

Things

Communicate

com·mu·ni·cate

/kəˈmyo͞onəˌkāt/

verb

verb: **communicate**; 3rd person present: **communicates**; past tense: **communicated**; past participle: **communicated**; gerund or present participle: **communicating**

1. share or exchange information, news, or ideas.
   "the prisoner was forbidden to **communicate with** his family"
   synonyms: be in touch, be in contact, have dealings, interface, interact, commune, meet, liaise; More
   - impart or pass on (information, news, or ideas).
     "he **communicated** his findings **to** the inspector"
     synonyms: convey, tell, impart, relay, transmit, pass on, announce, report, recount, relate, present; More
   - convey or transmit (an emotion or feeling) in a nonverbal way.
     "the ability of good teachers to communicate their own enthusiasm"
   - succeed in conveying one's ideas or in evoking understanding in others.
     "a politician must have the ability to communicate"
     synonyms: get one's message across, explain oneself, be understood,
     "learn how to communicate better"
   - (of two people) be able to share and understand each other's thoughts
   - pass on (an infectious disease) to another person or animal.
     synonyms: transmit, transfer, spread, carry, pass on
     "the disease is communicated easily"
   - transmit (heat or motion).
     "the heat is communicated through a small brass grating"
   - (of two rooms) have a common connecting door.
     "he went into the communicating room to pick up the phone"
     synonyms: connect with, join up with, open on to, lead into
     "each bedroom communicates with a bathroom"

verb

Share or Exchange Information

Communication(s)

com·mu·ni·ca·tion

/kəˌmyo͞onəˈkāSH(ə)n/

noun
noun: **communication**

1. the imparting or exchanging of information or news.
   "direct communication between the two countries will produce greater understanding"
   synonyms: transmission, conveyance, divulgence, disclosure; More
   - a letter or message containing information or news.
     plural noun: **communications**
     synonyms: message, statement, announcement, report, dispatch, communiqué, letter, bulletin, correspondence
     "an official communication"
   - the successful conveying or sharing of ideas and feelings.
     "there was a lack of **communication between** Pamela and her parents"
   - social contact.
     "she gave him some hope of her return, or at least of their future communication"
     synonyms: contact, dealings, relations, connection, association, socializing, intercourse; More
2. means of connection between people or places, in particular.
   - the means of sending or receiving information, such as telephone lines or computers.
     plural noun: **communications**
     "satellite communications"
   - the means of traveling or of transporting goods, such as roads or railroads.
     "a city providing excellent road and rail communications"
   - the field of study concerned with the transmission of information by various means.

Origin

late Middle English: from Old French *comunicacion*, from Latin *communicatio(n-)*, from the verb *communicare* 'to share' (see communicate).

Sharing or Exchanging of Information

Connectivity

Information Exchange Infrastructure

con·nec·tiv·i·ty

/kä¸nekˈtivədē,kə¸nekˈtivədē/

noun

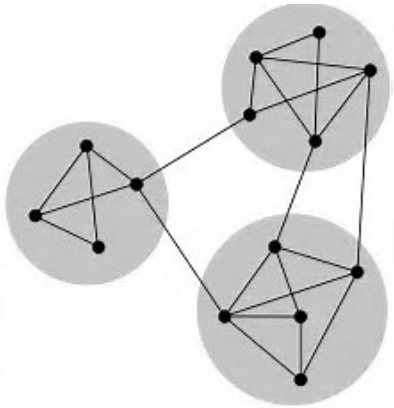
noun: **connectivity**

the state or extent of being connected or interconnected.

- COMPUTING

  capacity for the interconnection of platforms, systems, and applications.

  "connectivity between Sun and Mac platforms"



noun

Use over time for: connectivity

in·fra·struc·ture

/ˈinfrə¸strək(t)SHər/

noun

noun: **infrastructure**; plural noun: **infrastructures**

the basic physical and organizational structures and facilities (e.g., buildings, roads, and power supplies) needed for the operation of a society or enterprise.

Use over time for: infrastructure

Interoperability

in·ter·op·er·a·bil·i·ty

/ˌin(t)ərˌäp(ə)rəˈbilədē/

noun

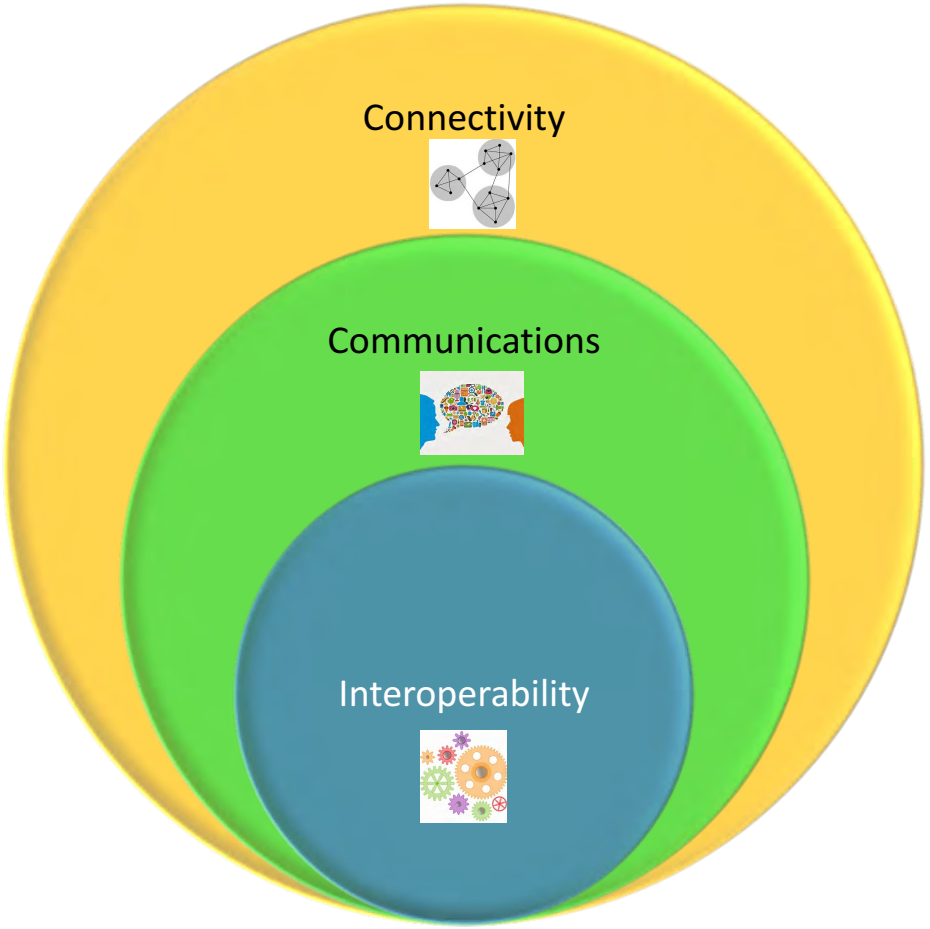
the ability of computer systems or software to exchange and make use of information.
"interoperability between devices made by different manufacturers"

- the ability of military equipment or groups to operate in conjunction with each other.
  "staff believe interoperability between forces is crucial to effectiveness"

Use over time for: interoperability

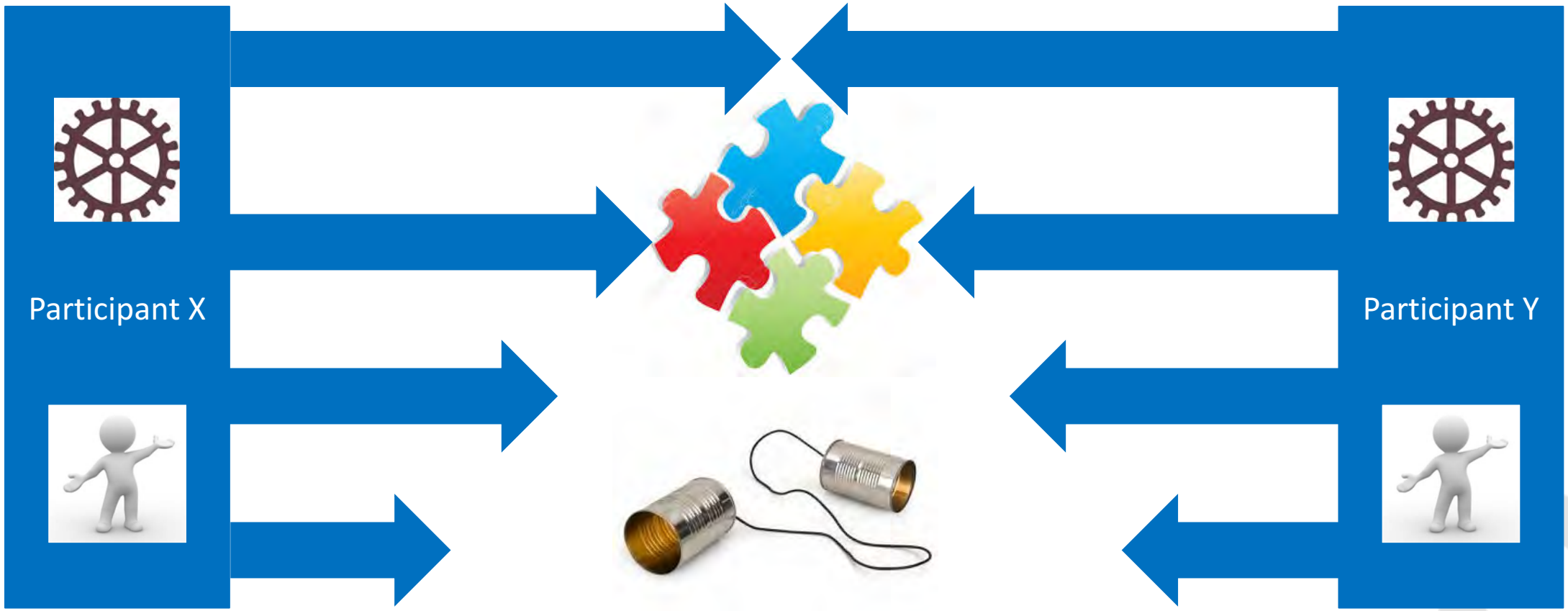
Ability to Exchange and Make Use of Information

Connectivity → Communications → Interoperability



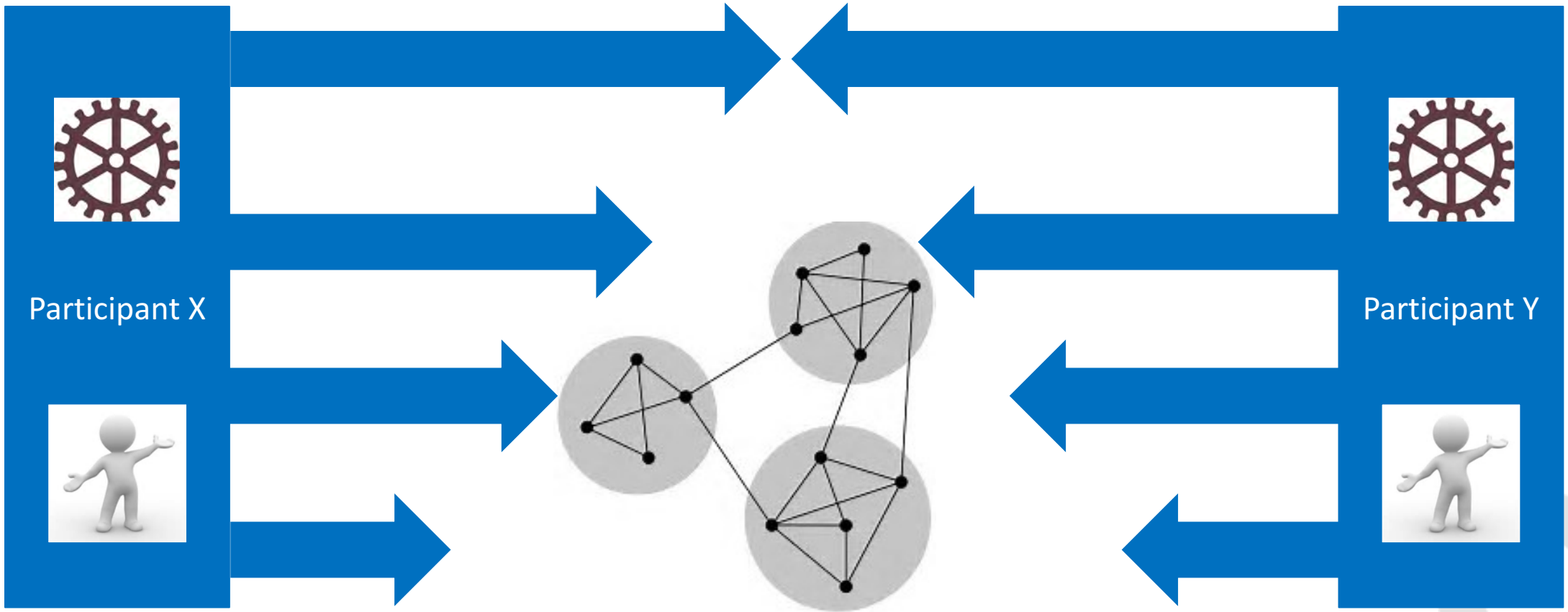
Interoperability requires
a
Suitable Connectivity Infrastructure
for
Meaningful Communications between…

People vs. Things...

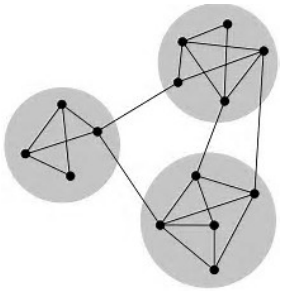


Connectivity infrastructure provides support for Interoperability

Directly impacts ease of integration, interoperability, and composability



So, how do we go from here to there?



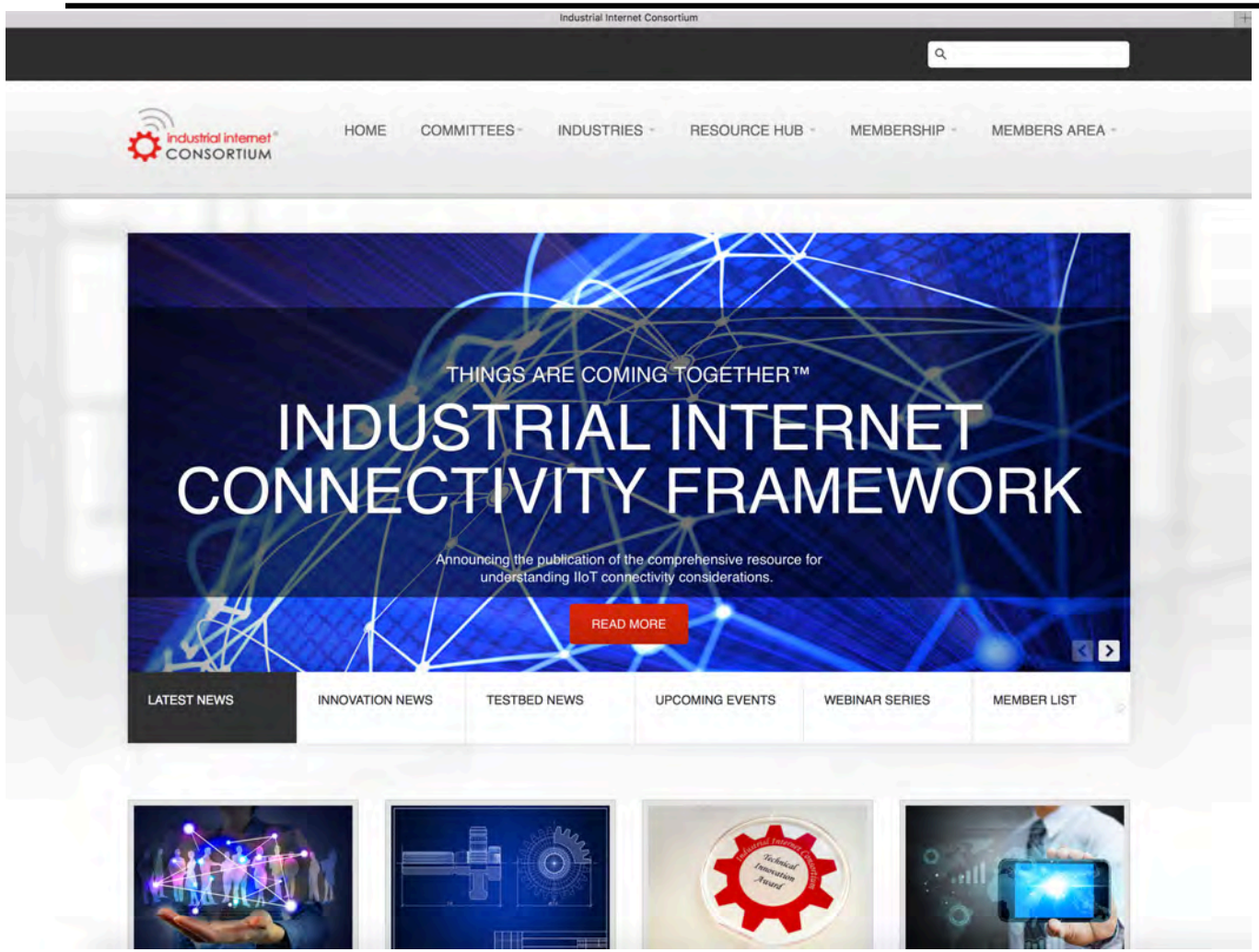
?

People

Internet of

Things

Industrial Internet Connectivity Framework (IICF): Feb 28, 2017



https://www.iiconsortium.org/IICF.htm

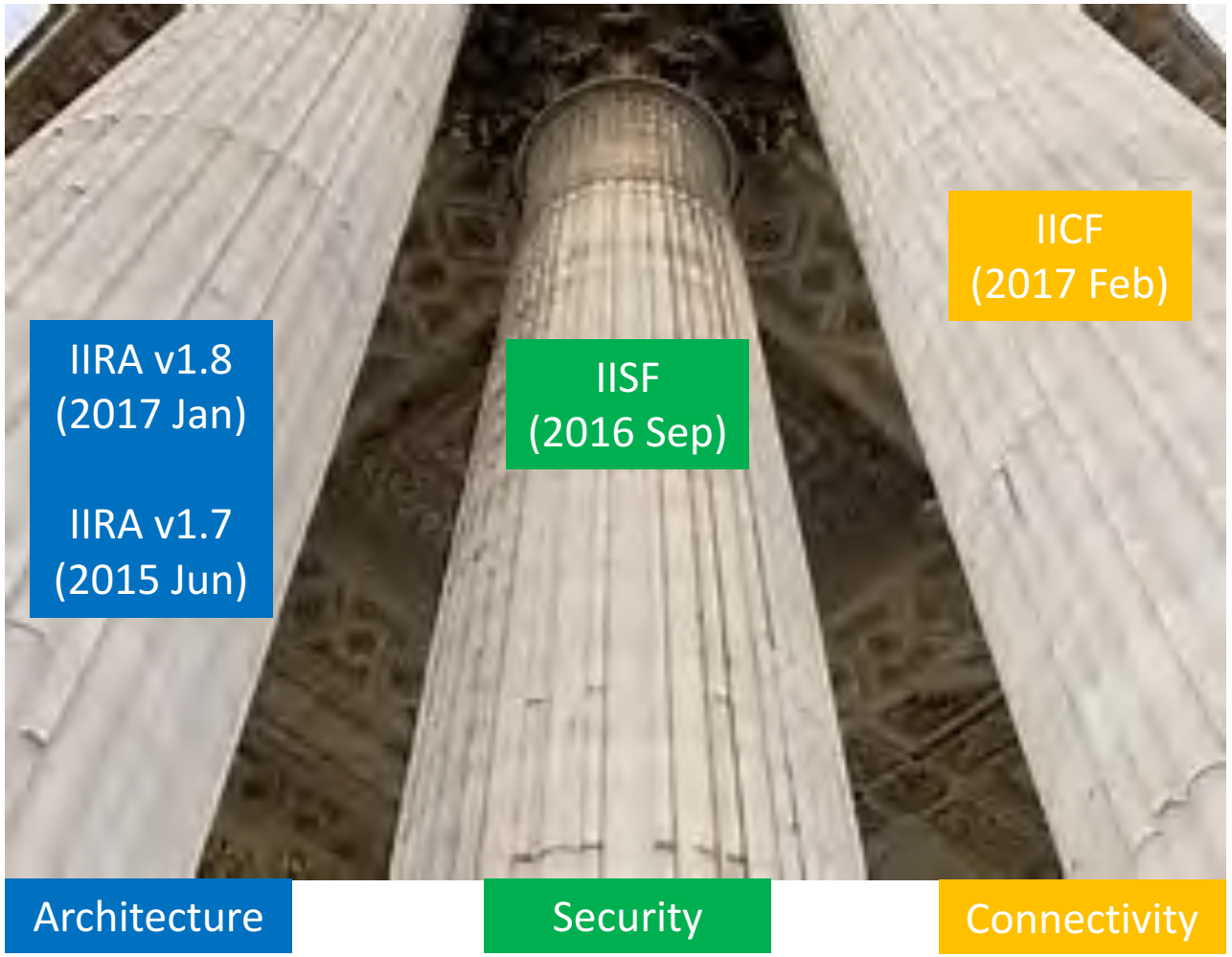
Comprehensive treatment of connectivity

As a means of building interoperable IIoT systems

DOWNLOAD PDF

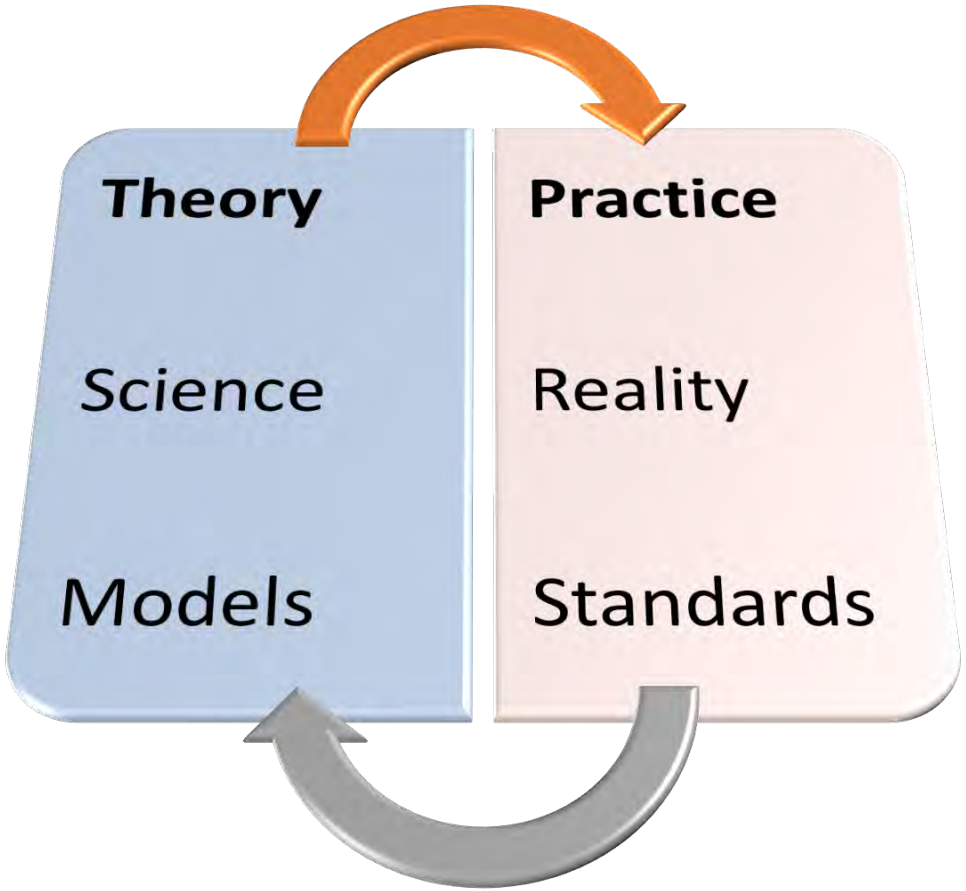
IICF FAQ

IIoT Technical Foundation....Things are Coming Together!



www.iiconsortium.org

IICF: Theory + Practice = Useful Guidance



Industrial Internet Connectivity Framework (IICF) Goals

Accelerating IIoT

Guide map to the rich but often confusing landscape of IIoT connectivity

Clarity

Sets a stable long term foundation for IIoT interoperability

Foundation

Guidance

Useful, practical, tangible guidance for requirements assessment, technology evaluation and selection

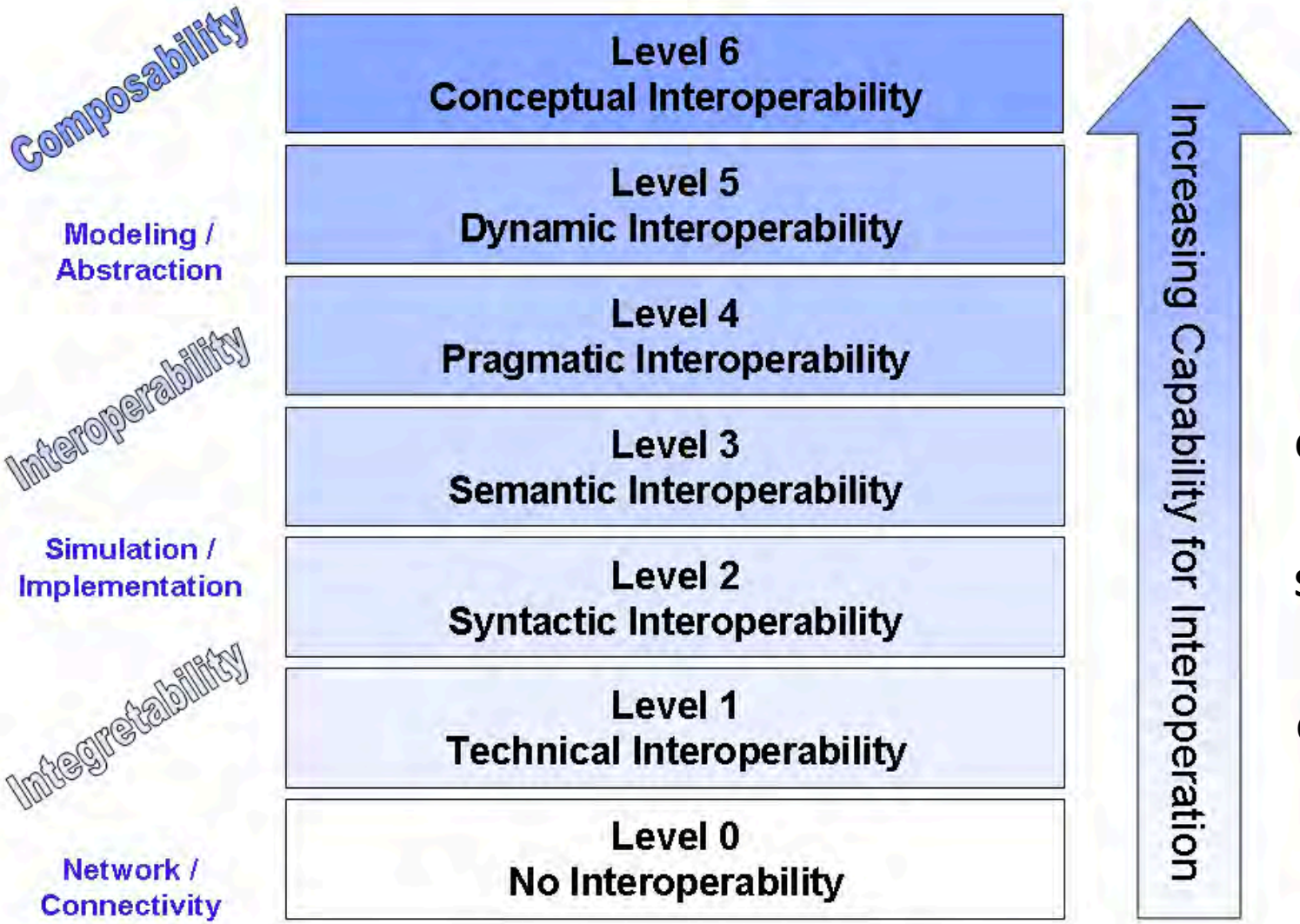
Evolution of the IIoT Connectivity Stack

Connectivity Framework

Connectivity Transport

Core Functions & Typical Considerations

Levels of Interoperability



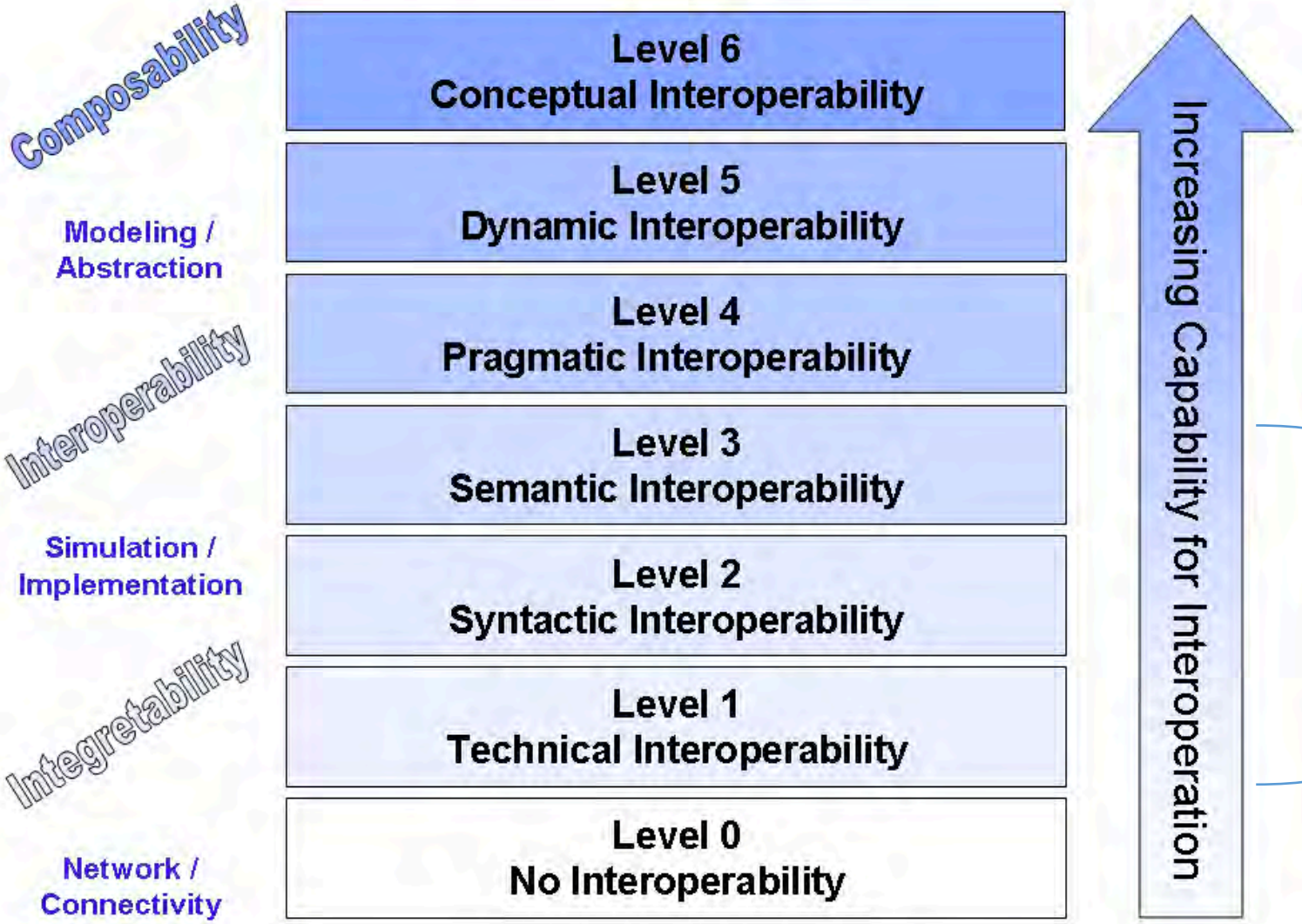
Context of data objects is also shared

Structure of data is also shared

Compatible means of signaling and protocols

http://en.wikipedia.org/wiki/Conceptual_interoperability

Historically: Vertical silos of interoperability



http://en.wikipedia.org/wiki/Conceptual_interoperability

Historically

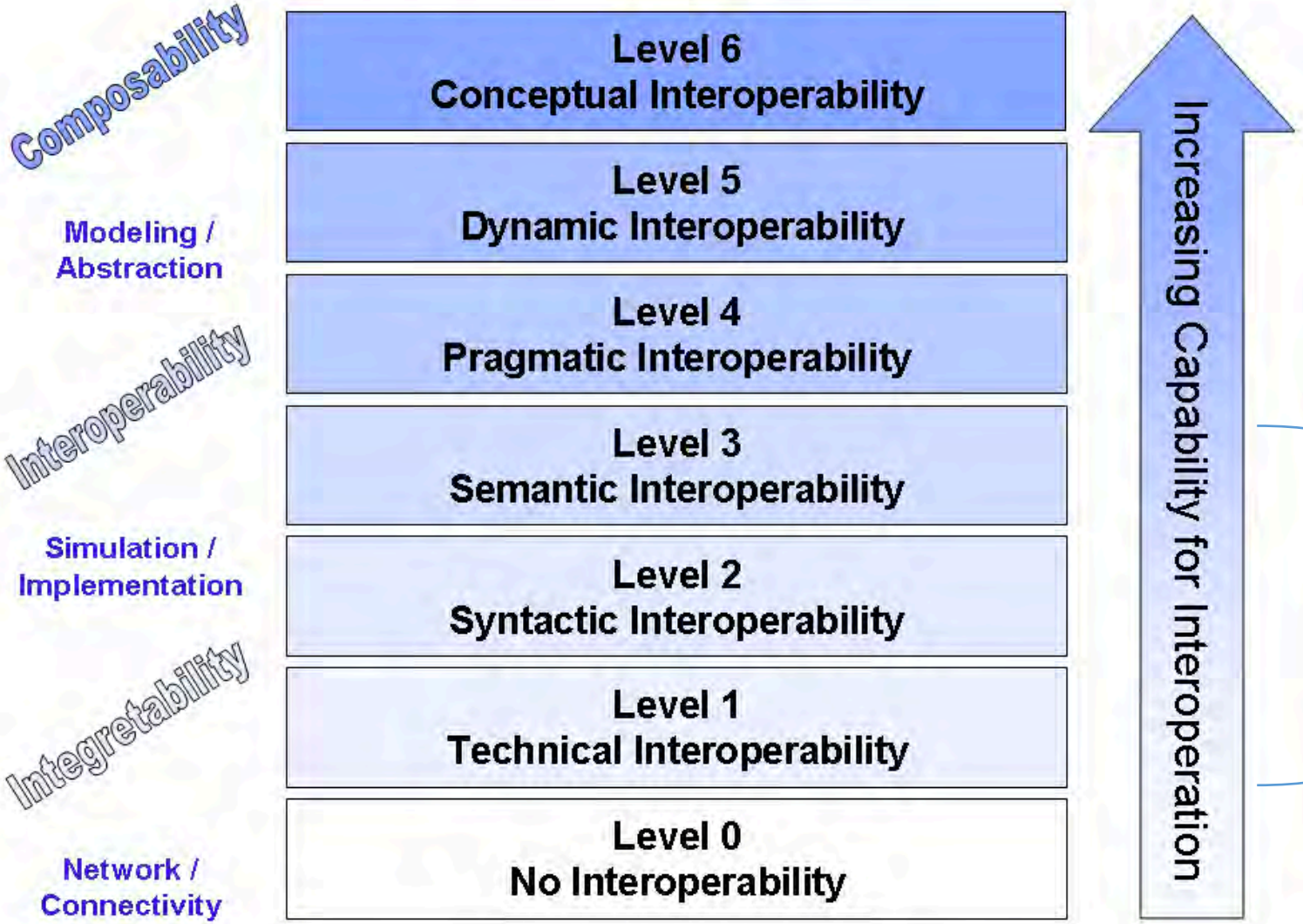
MANY **Vertical** Specific Stacks

Often Proprietary

Example Verticals:

- SCADA
- Industrial Automation
- Electric Utilities
- Medical
- :

Future: Horizontal interoperability



Industrial Internet (IIoT)

Vertical Industry Data Models

Connectivity Framework

Connectivity Transport

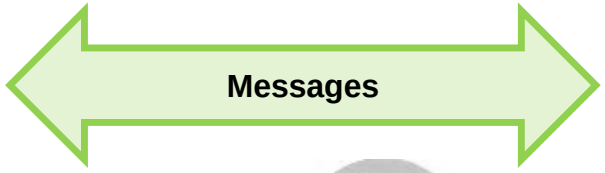
Horizontal stack that can span across verticals!

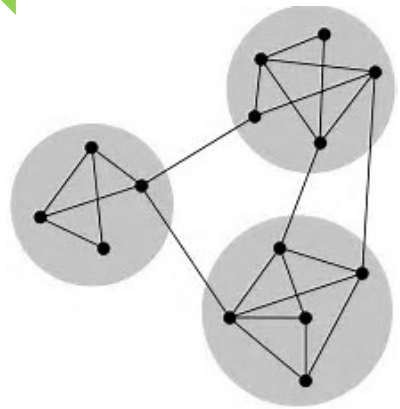
http://en.wikipedia.org/wiki/Conceptual_interoperability

Technical Interoperability Example…

Share byte sequences

```
0000  54 a0 50 cf b6 80 14 10  9f e2 3a 05 08 00 45 00   T.P..... ..:...E.
0010  00 90 4a ec 00 00 40 11  07 d4 c0 a8 59 e6 0a 00   ..J...@. ....Y...
0020  03 0f f4 22 1c f3 00 7c  f3 13 52 54 50 53 02 01   ..."...| ..RTPS..
0030  01 01 c0 a8 59 e6 00 00  49 03 00 00 00 01 09 01   ....Y... I.......
0040  08 00 1a b6 c9 58 d6 7f  2b f1 15 07 50 00 00 00   .....X.. +...P...
0050  10 00 00 00 00 00 80 00  00 02 00 00 00 00 59 02   ........ ......Y.
0060  00 00 70 00 10 00 ca c2  17 c3 18 36 3f 8e f1 16   ..p..... ...6?...
0070  0e ee de f9 e8 86 01 00  01 00 00 01 00 00 05 00   ........ ........
0080  00 00 42 4c 55 45 00 00  00 00 55 00 00 00 f1 00   ..BLUE.. ..U.....
0090  00 00 1e 00 00 00 00 00  00 00 00 00 00 00        ........ ......
```



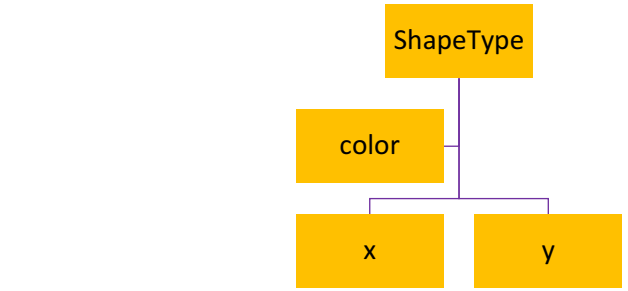


Technical Interoperability Example…

Share byte sequences

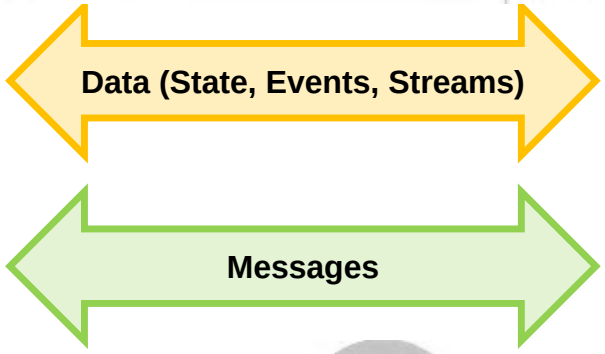
```
0000  54 a0 50 cf b6 80 14 10  9f e2 3a 05 08 00 45 00   T.P..... ..:...E.
0010  00 90 4a ec 00 00 40 11  07 d4 c0 a8 59 e6 0a 00   ..J...@. ....Y...
0020  03 0f f4 22 1c f3 00 7c  f3 13 52 54 50 53 02 01   ..."...| ..RTPS..
0030  01 01 c0 a8 59 e6 00 00  49 03 00 00 00 01 09 01   ....Y... I.......
0040  08 00 1a b6 c9 58 d6 7f  2b f1 15 07 50 00 00 00   .....X.. +...P...
0050  10 00 00 00 00 00 80 00  00 02 00 00 00 00 59 02   ........ ......Y.
0060  00 00 70 00 10 00 ca c2  17 c3 18 36 3f 8e f1 16   ..p..... ...6?...
0070  0e ee de f9 e8 86 01 00  01 00 00 01 00 00 05 00   ........ ........
0080  00 00 42 4c 55 45 00 00  00 00 55 00 00 00 f1 00   ..BLUE.. ..U.....
0090  00 00 1e 00 00 00 00 00  00 00 00 00 00 00        ........ ......
```

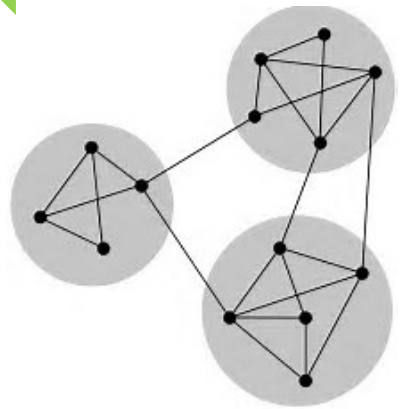
Syntactic Interoperability Example…



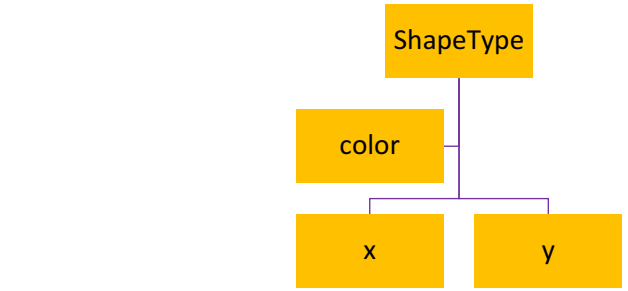
Share structured datatypes

ShapeType	ShapeType
color (key)	string<128>
x	long
y	long



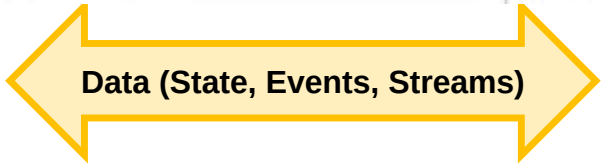


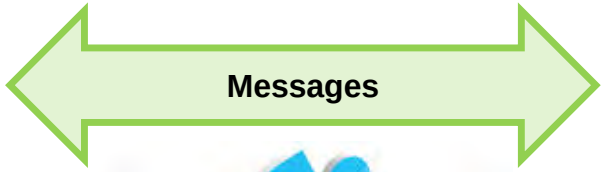
Syntactic Interoperability Example…



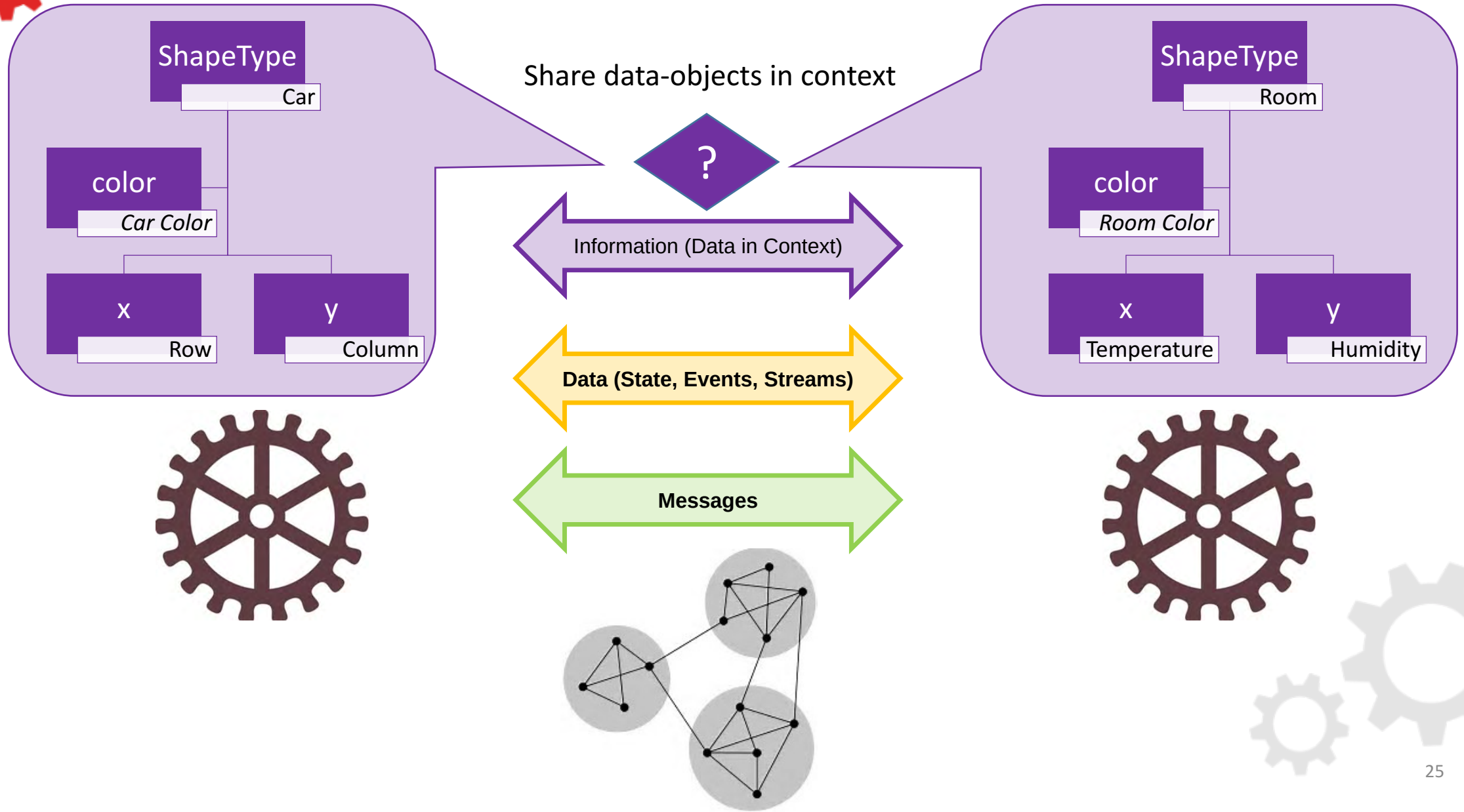
Share structured datatypes

ShapeType	ShapeType
color (key)	string<128>
x	long
y	long

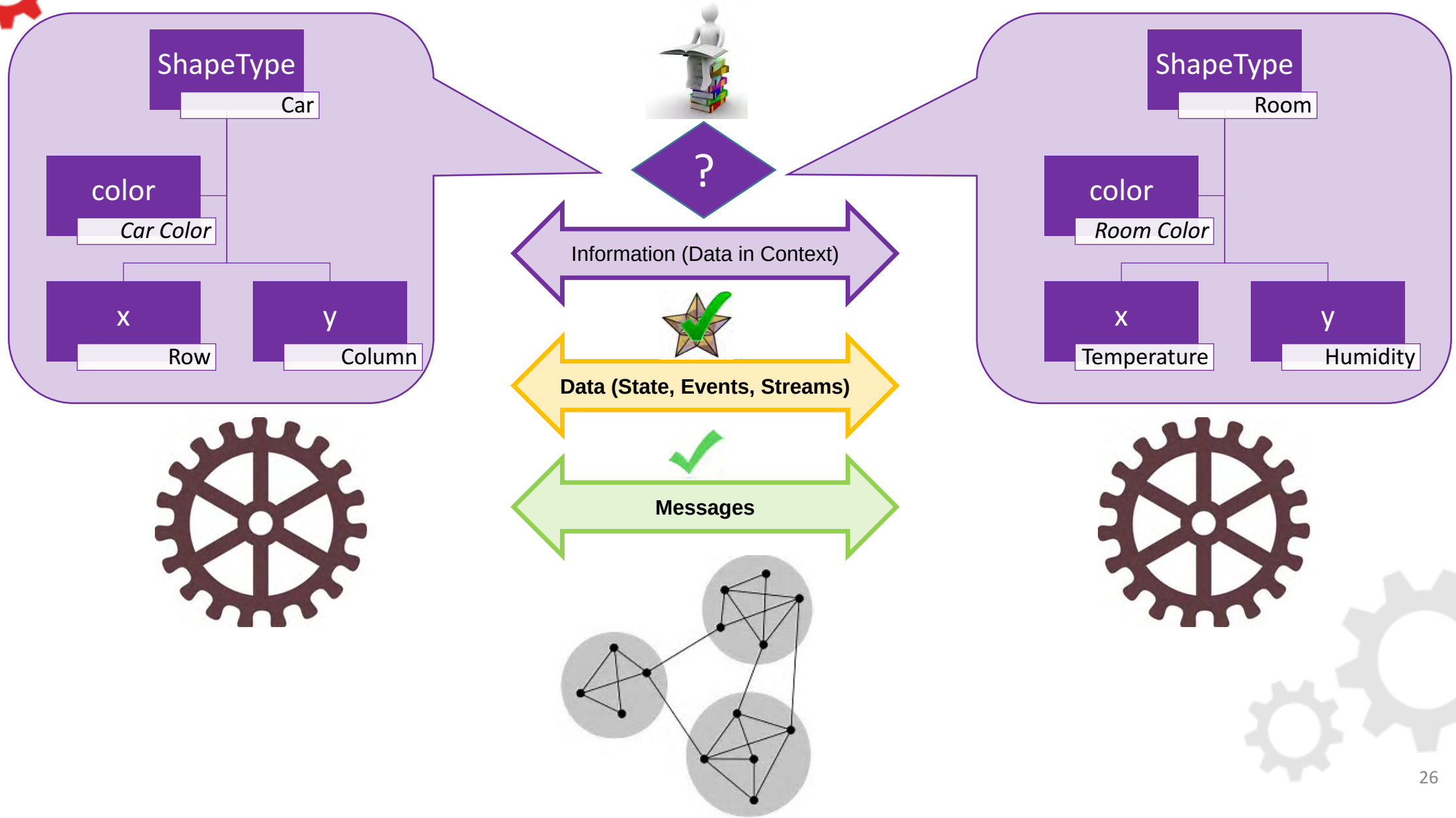




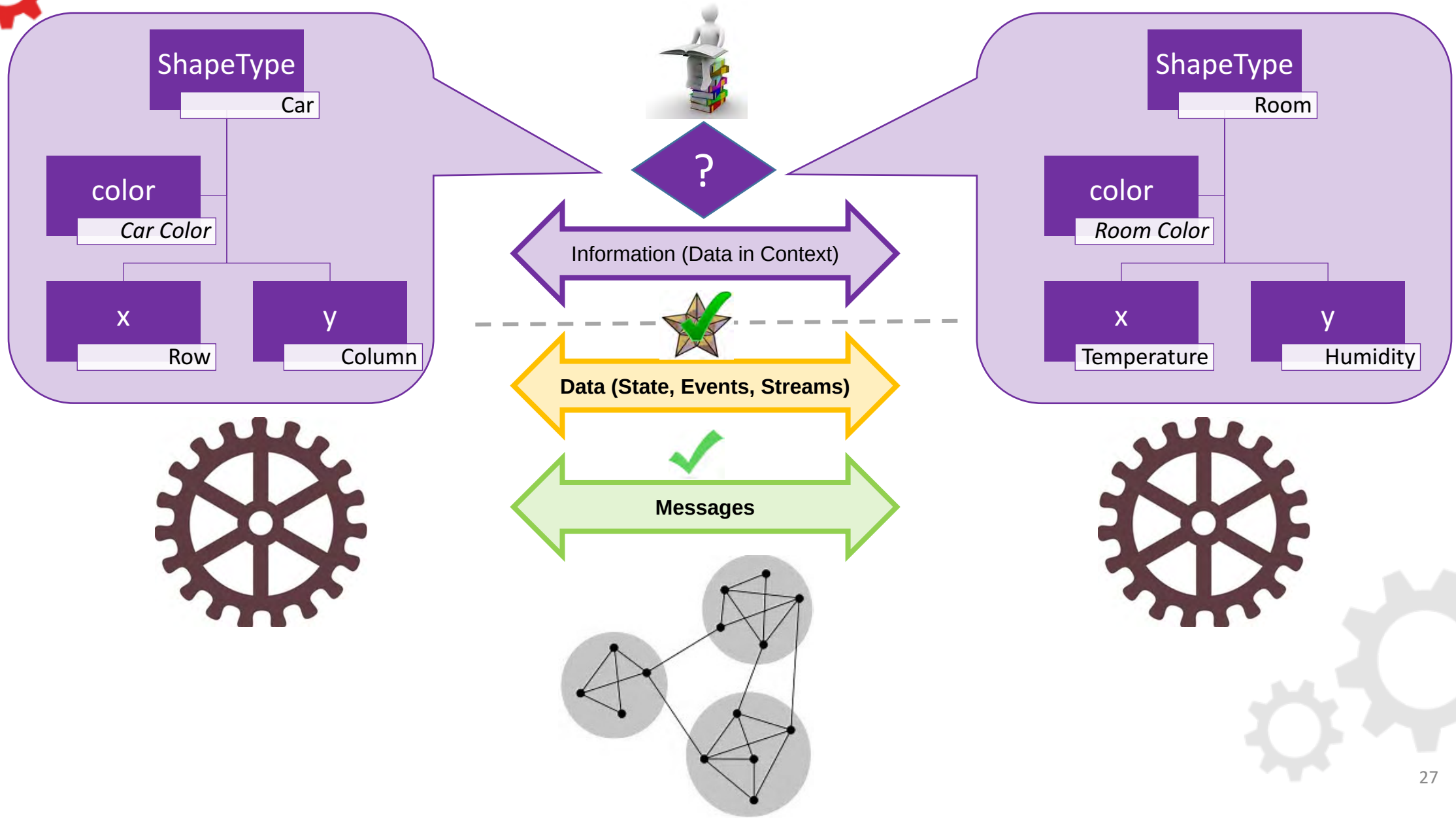
Semantic Interoperability Example…



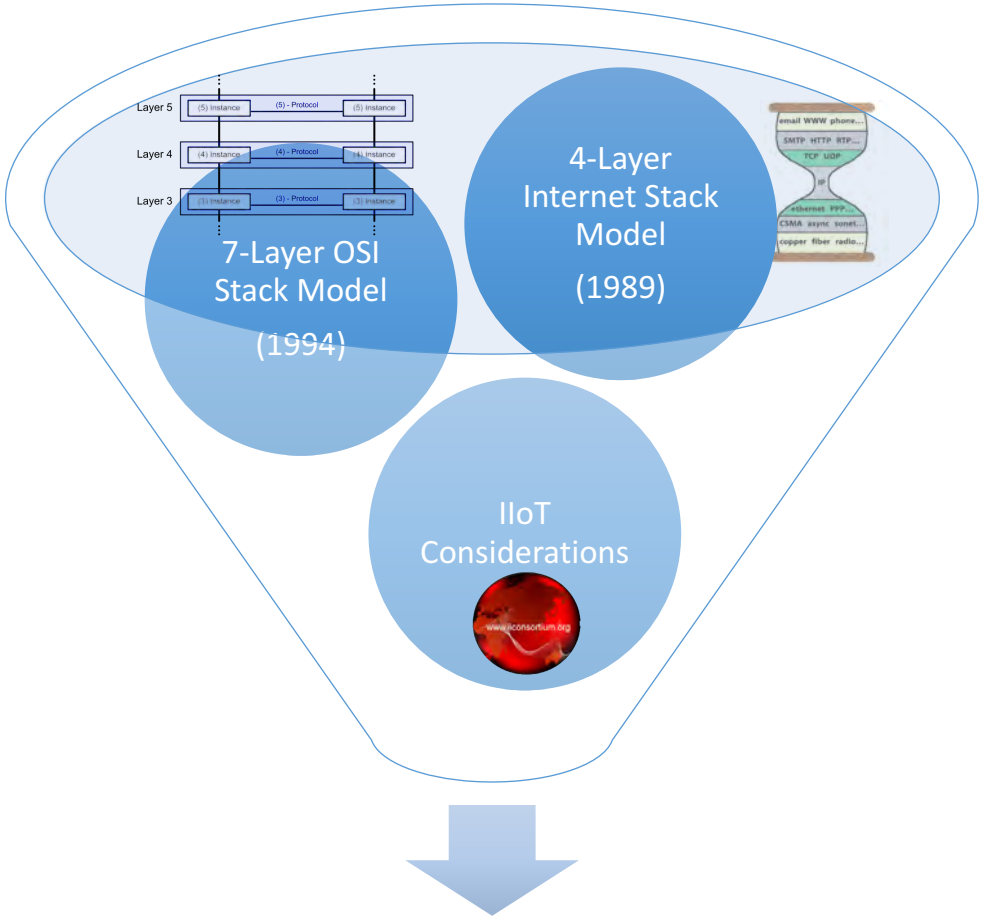
Where do we draw the line?



Where do we draw the line?

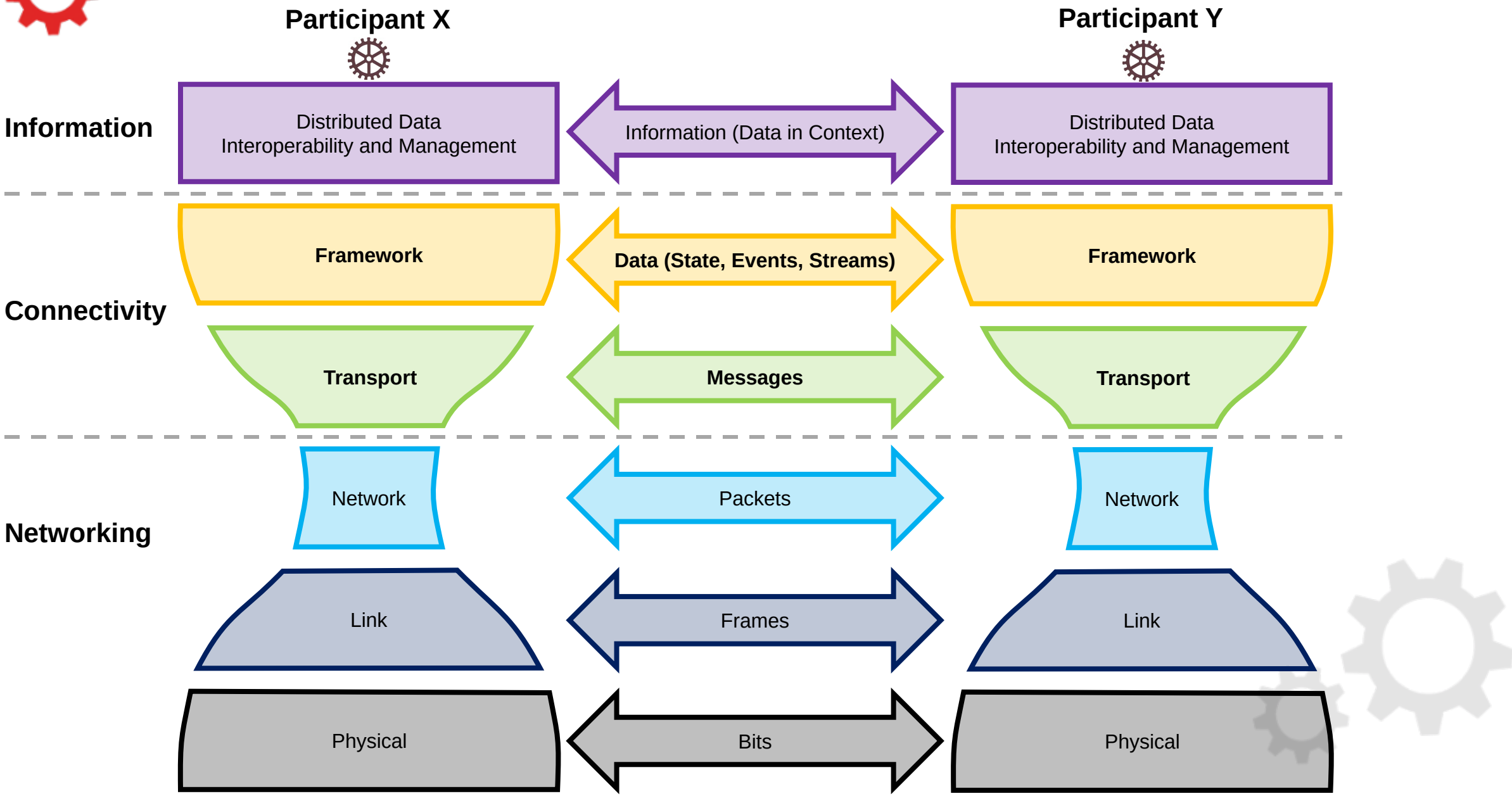


Evolution of the IIoT Connectivity Stack

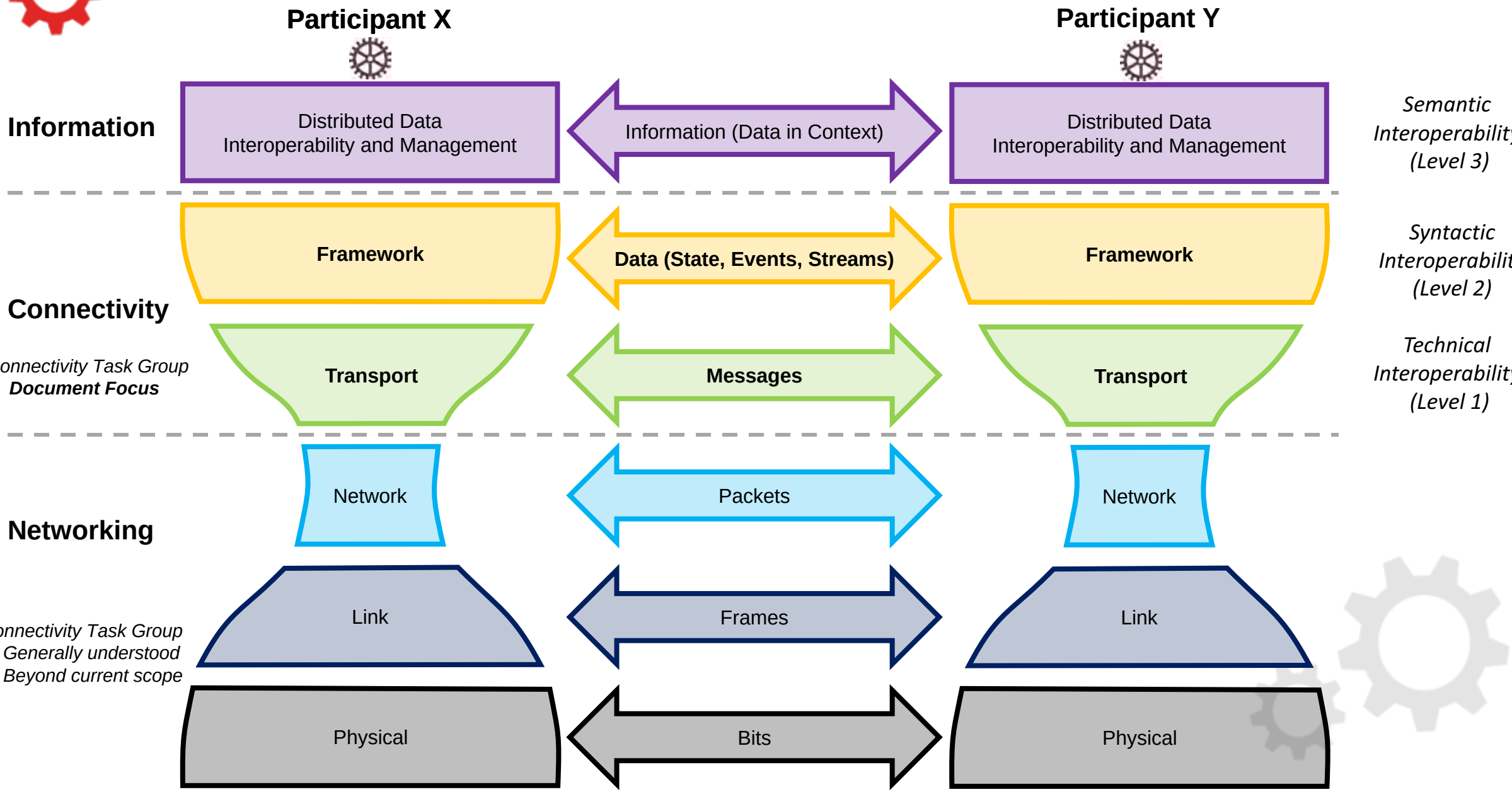


IIoT Connectivity Stack Model (2017)

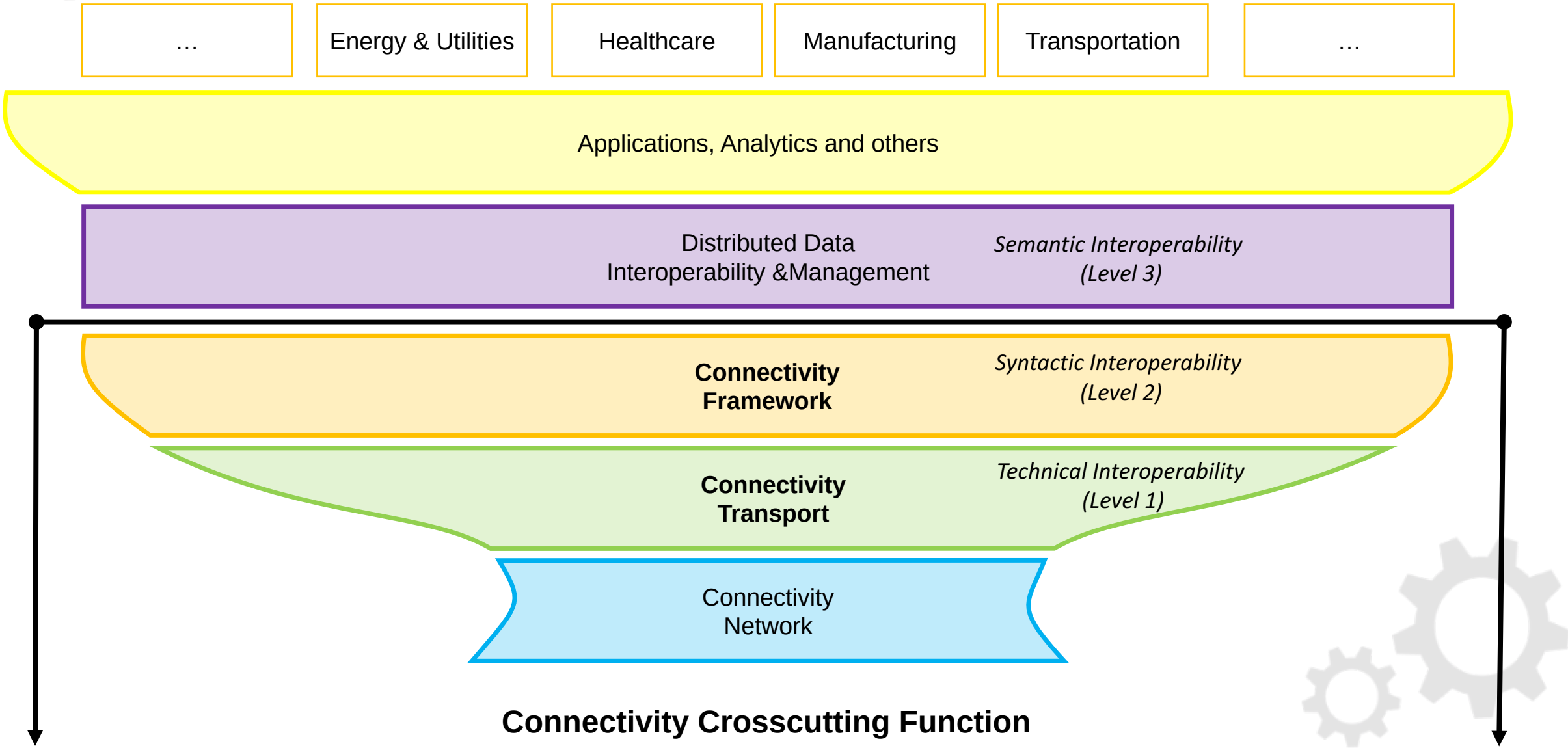
IIoT Connectivity Stack Model



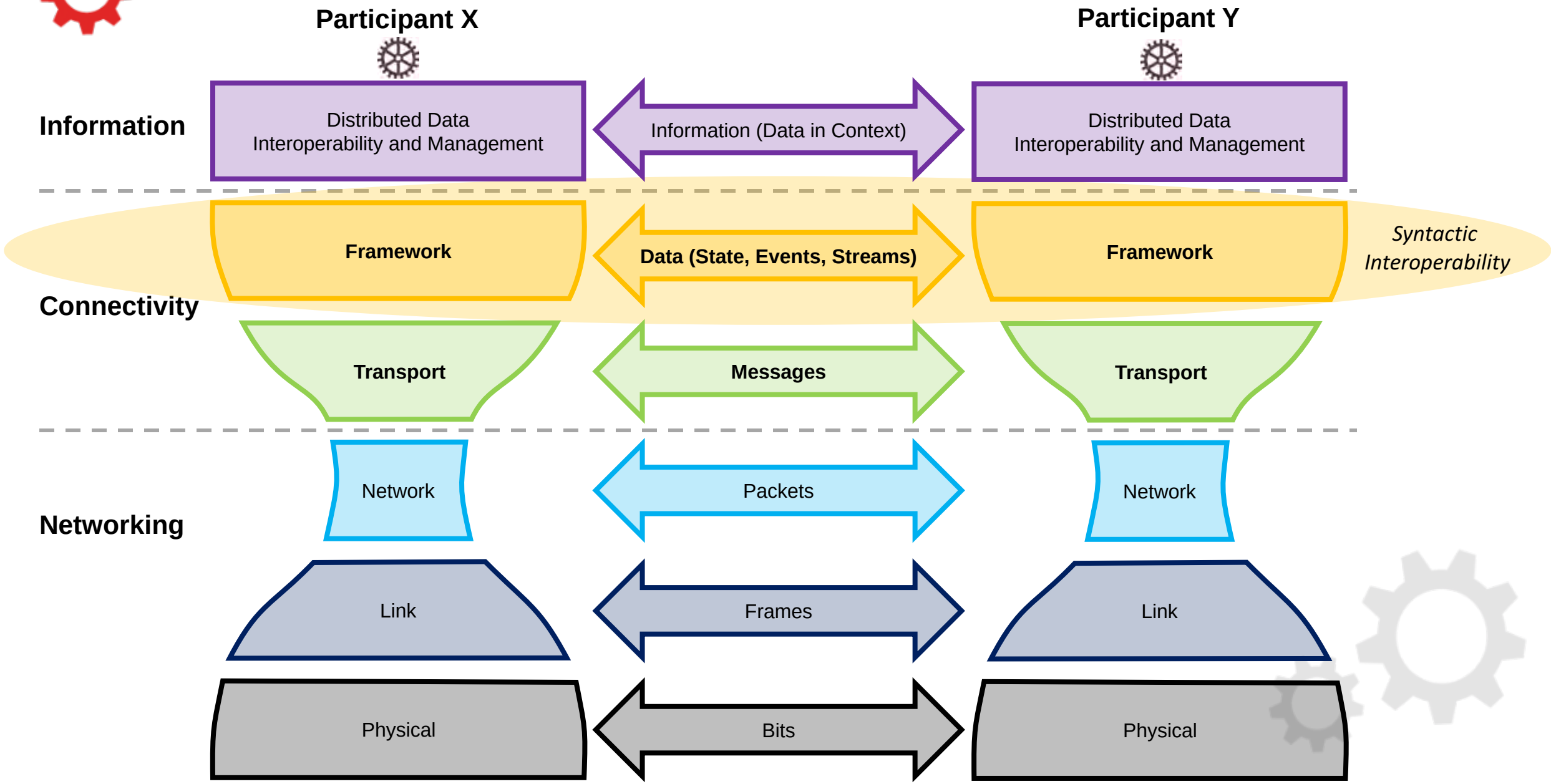
IIoT Connectivity Stack Model



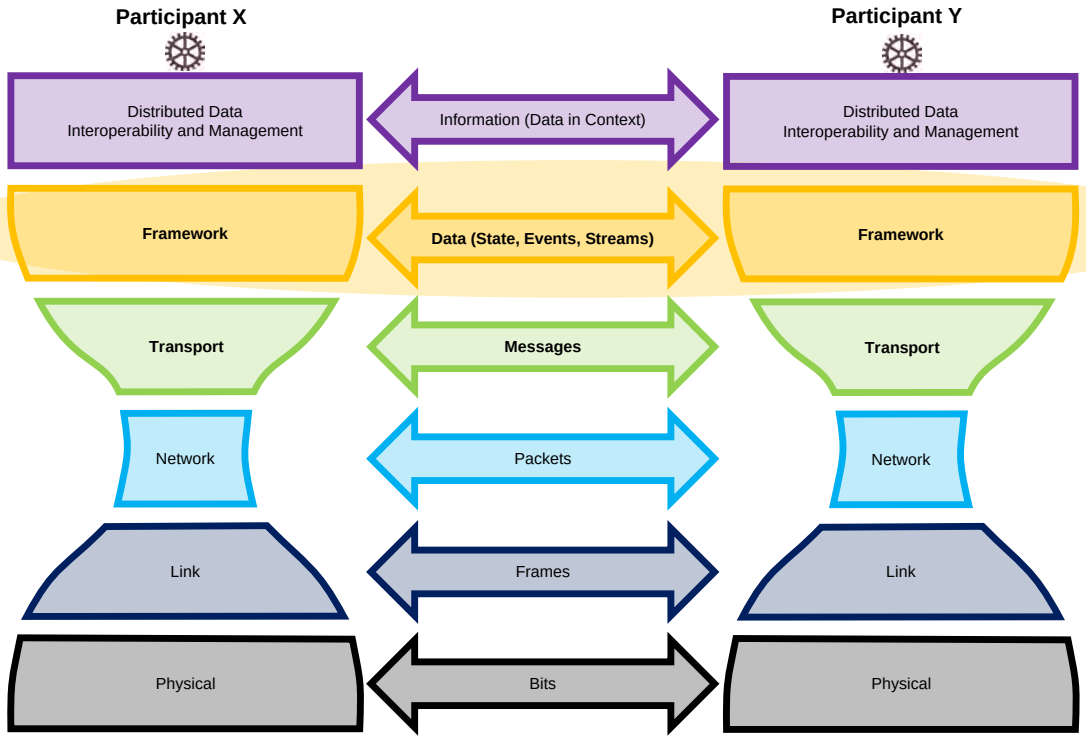
IIoT Horizontal Interoperability



IIoT Connectivity Stack



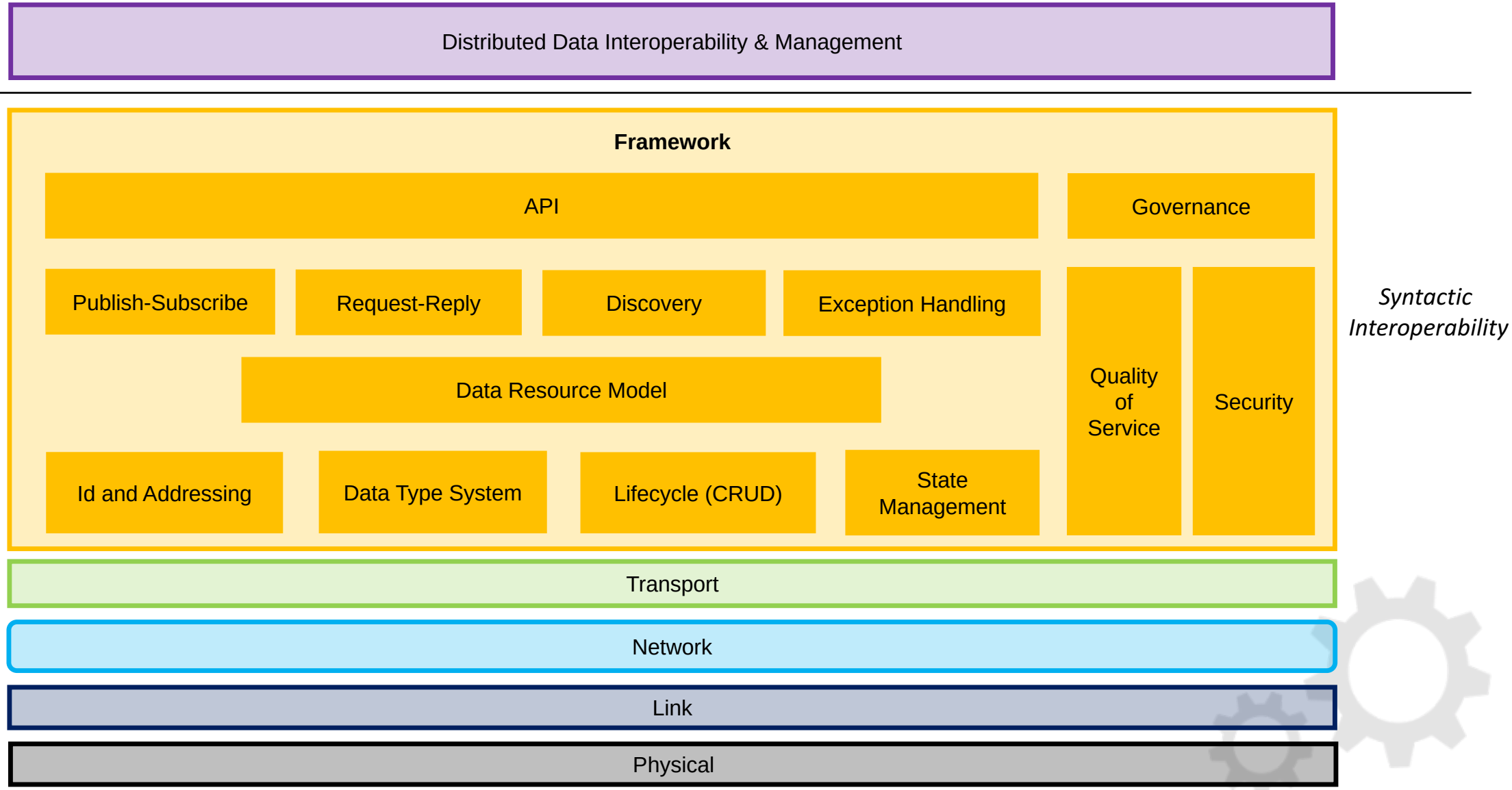
Framework Layer : Syntactic Interoperability



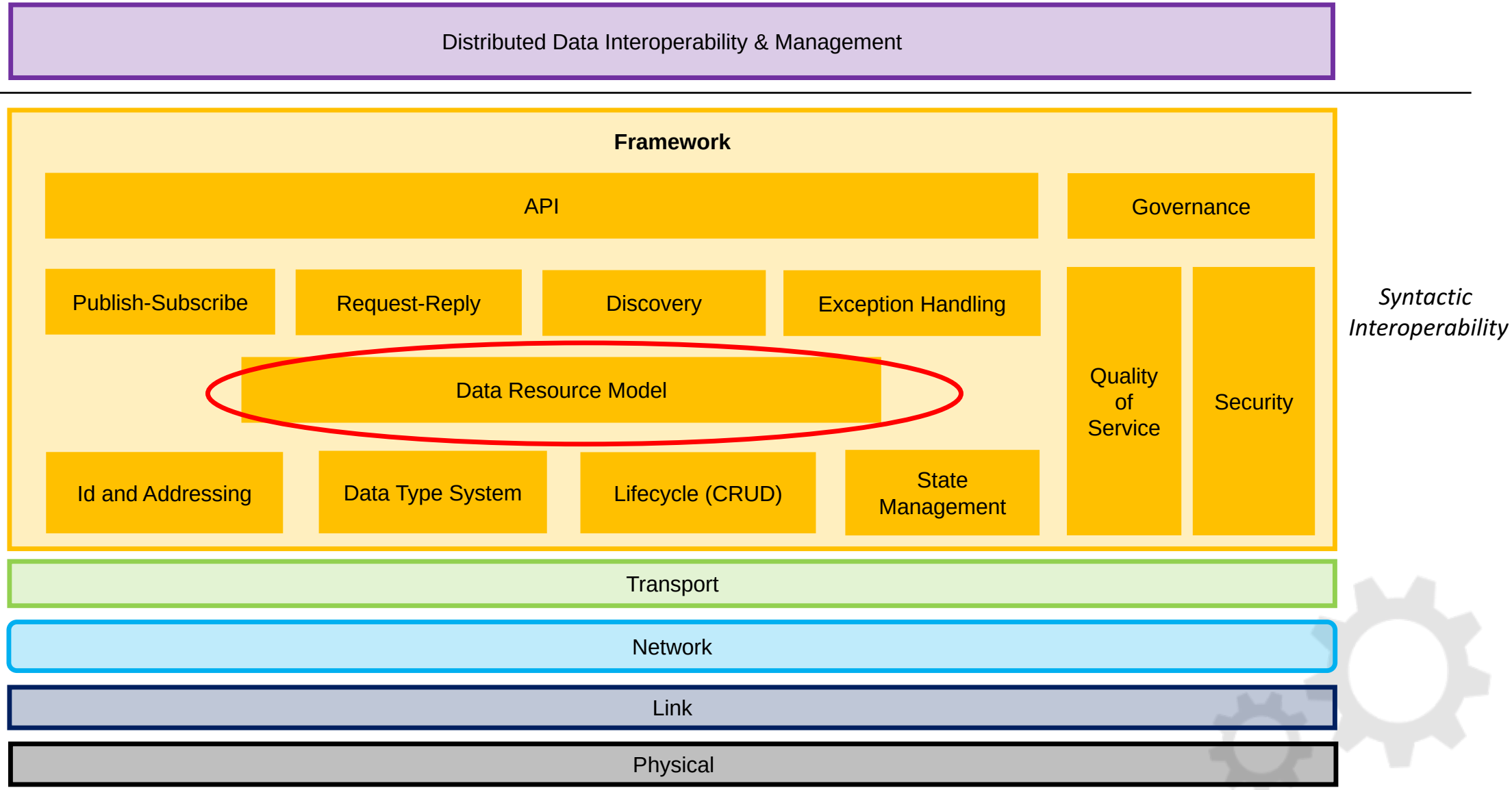
Connectivity Framework Layer

- Provides ***syntactic interoperability*** between endpoints
  - Share structured datatypes
    - Information is structured in a common and unambiguous data format
  - Meaning (interpretation of datatypes in context) is beyond the scope of this layer
- Connectivity Framework Layer Infrastructure
  - Any programming environment
  - Any computing platform
  - May observe data flows & optimize datatype sharing and delivery

Connectivity Framework Layer



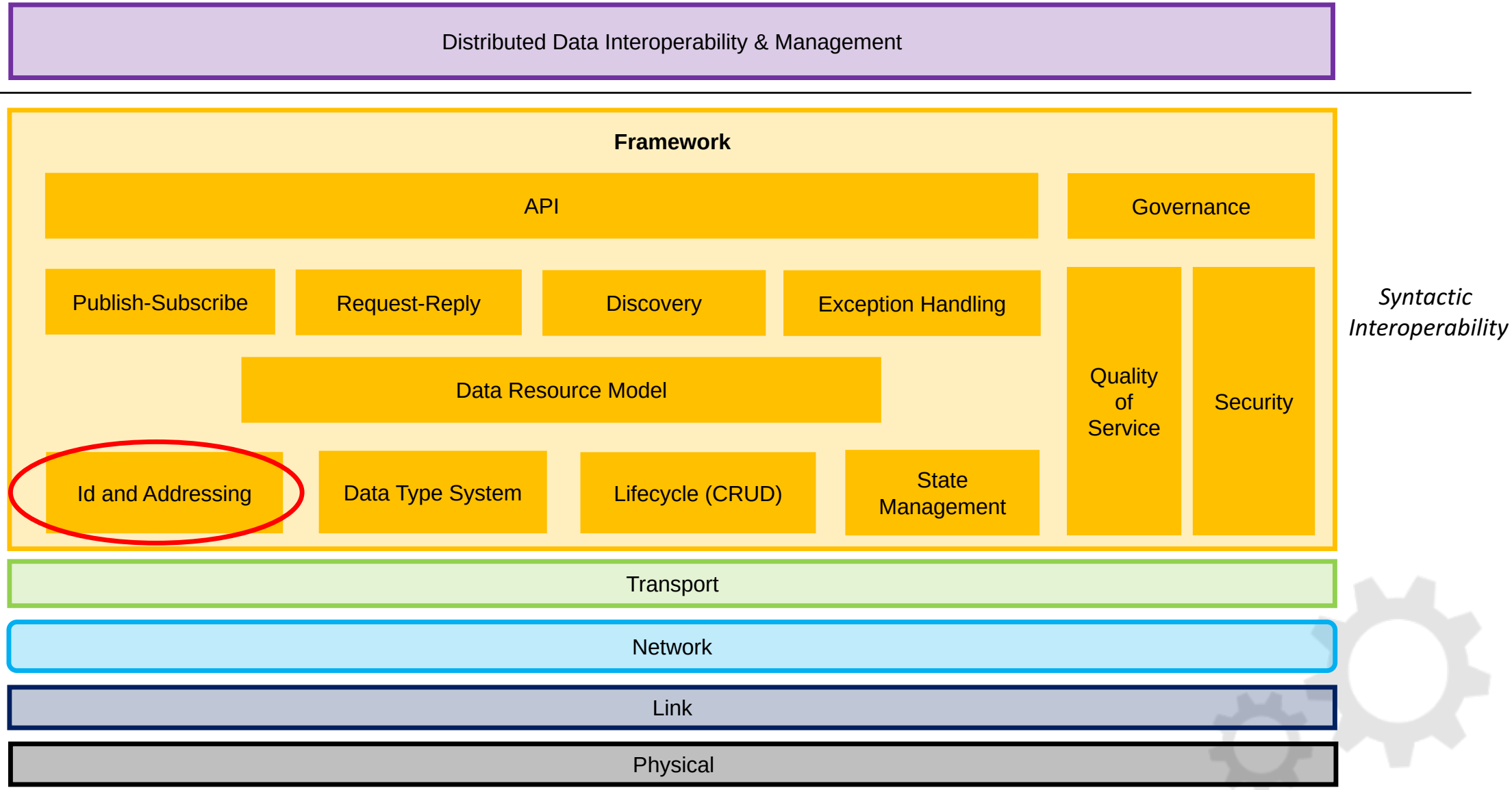
Connectivity Framework Layer



Connectivity Framework Functions

Syntactic Interoperability

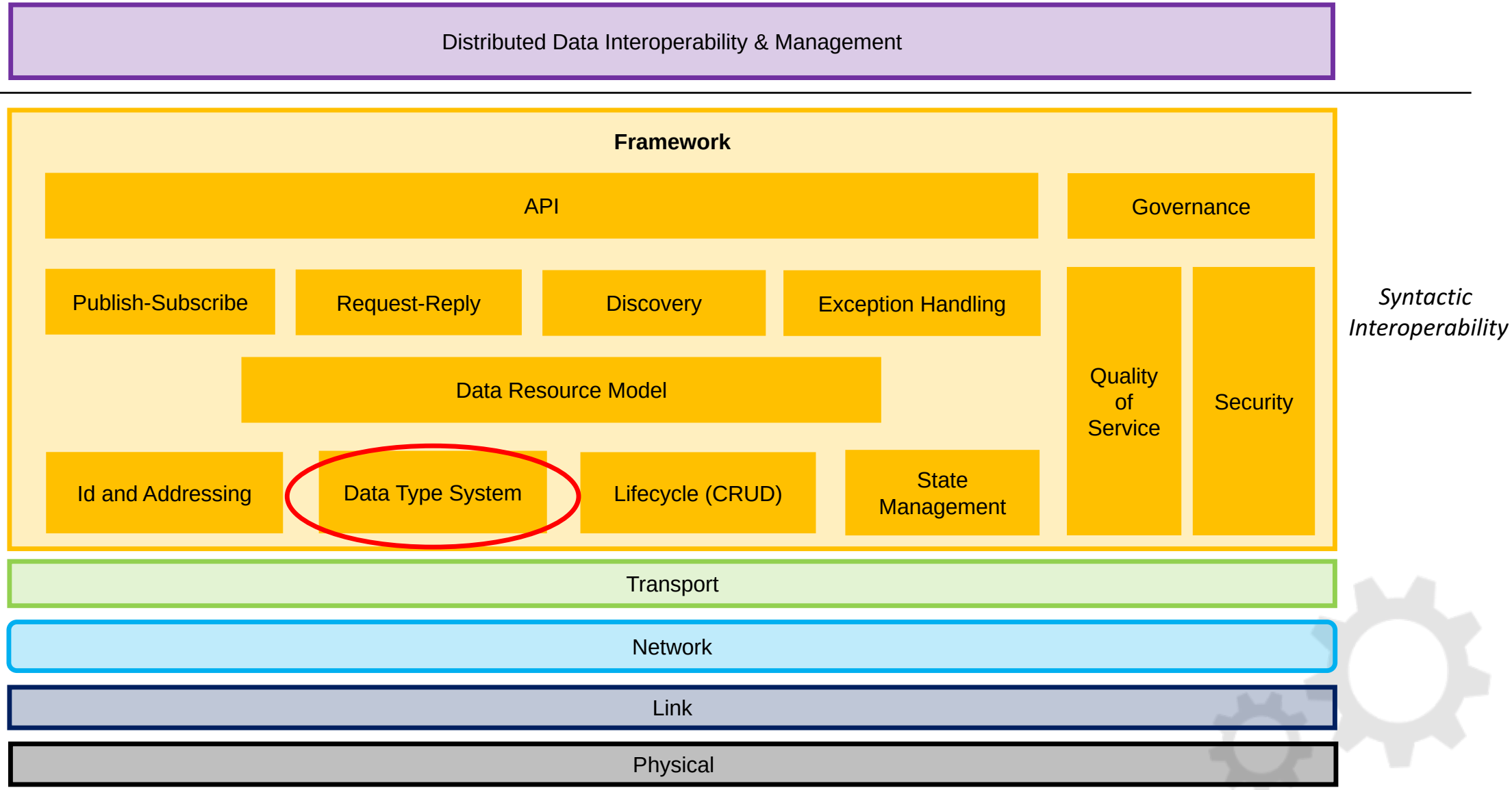
Connectivity Framework Layer



Connectivity Framework Functions

Syntactic Interoperability

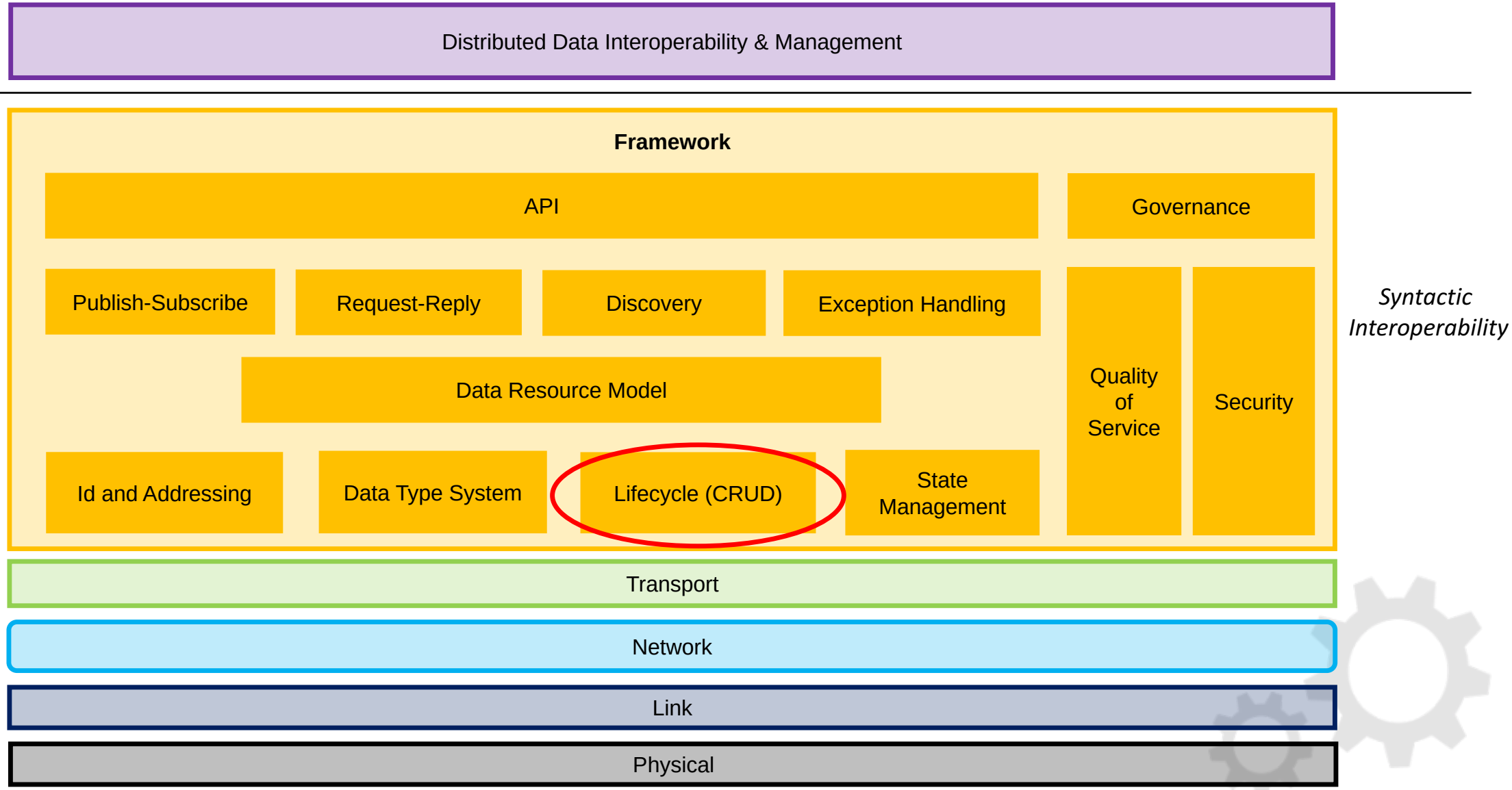
Connectivity Framework Layer



Connectivity Framework Functions

Syntactic Interoperability

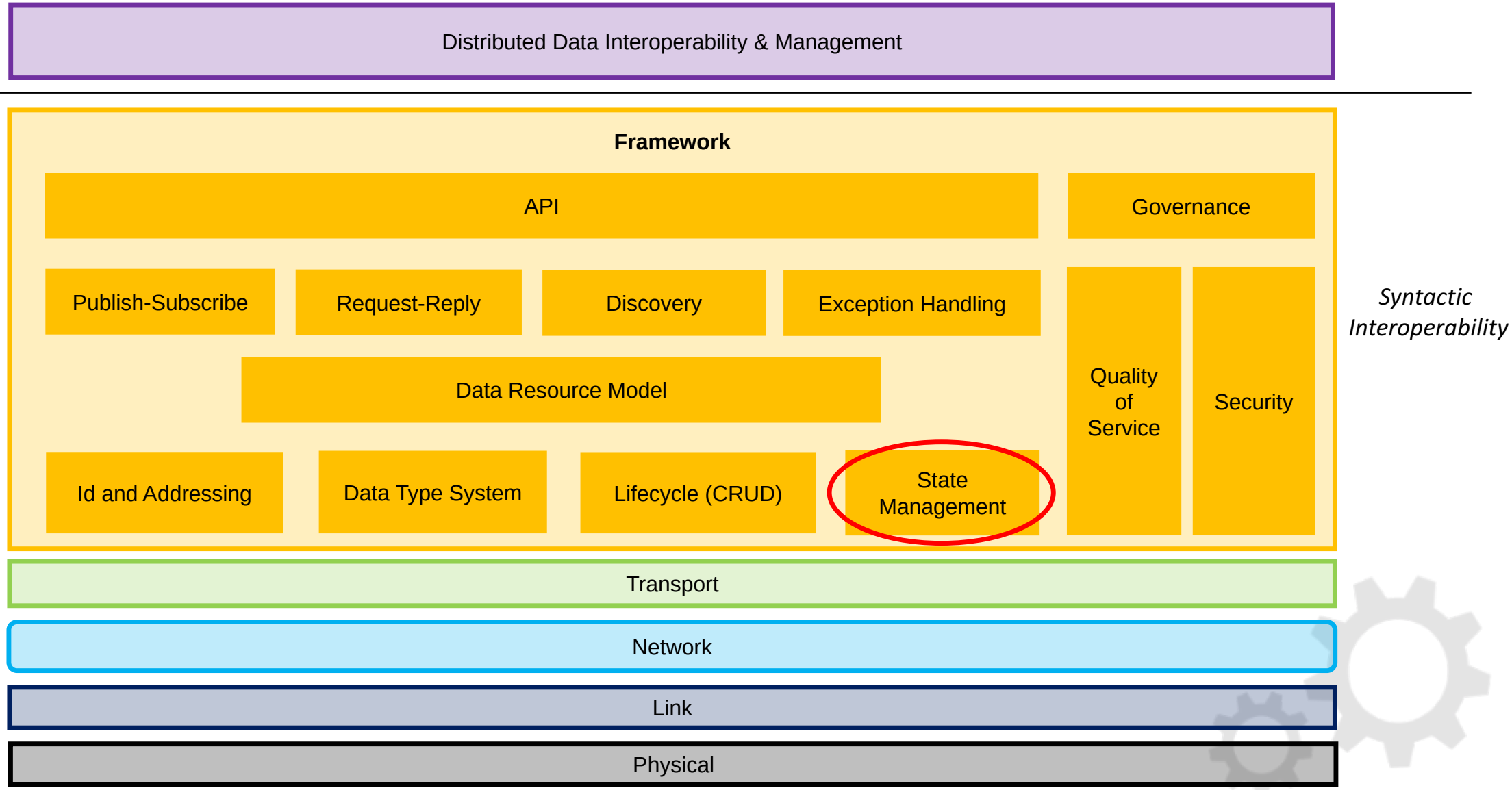
Connectivity Framework Layer



Connectivity Framework Functions

Syntactic Interoperability

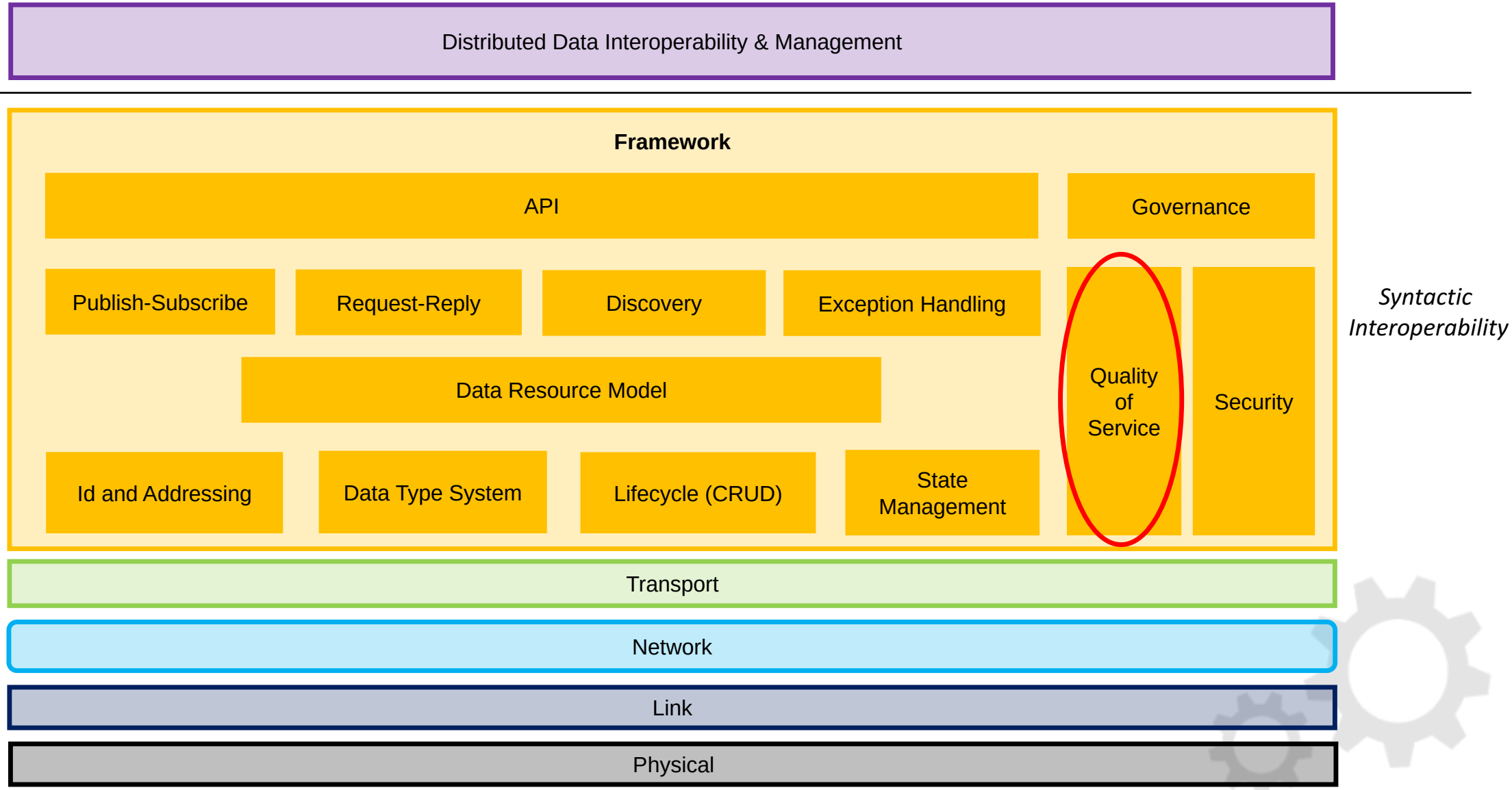
Connectivity Framework Layer



Connectivity Framework Functions

Syntactic Interoperability

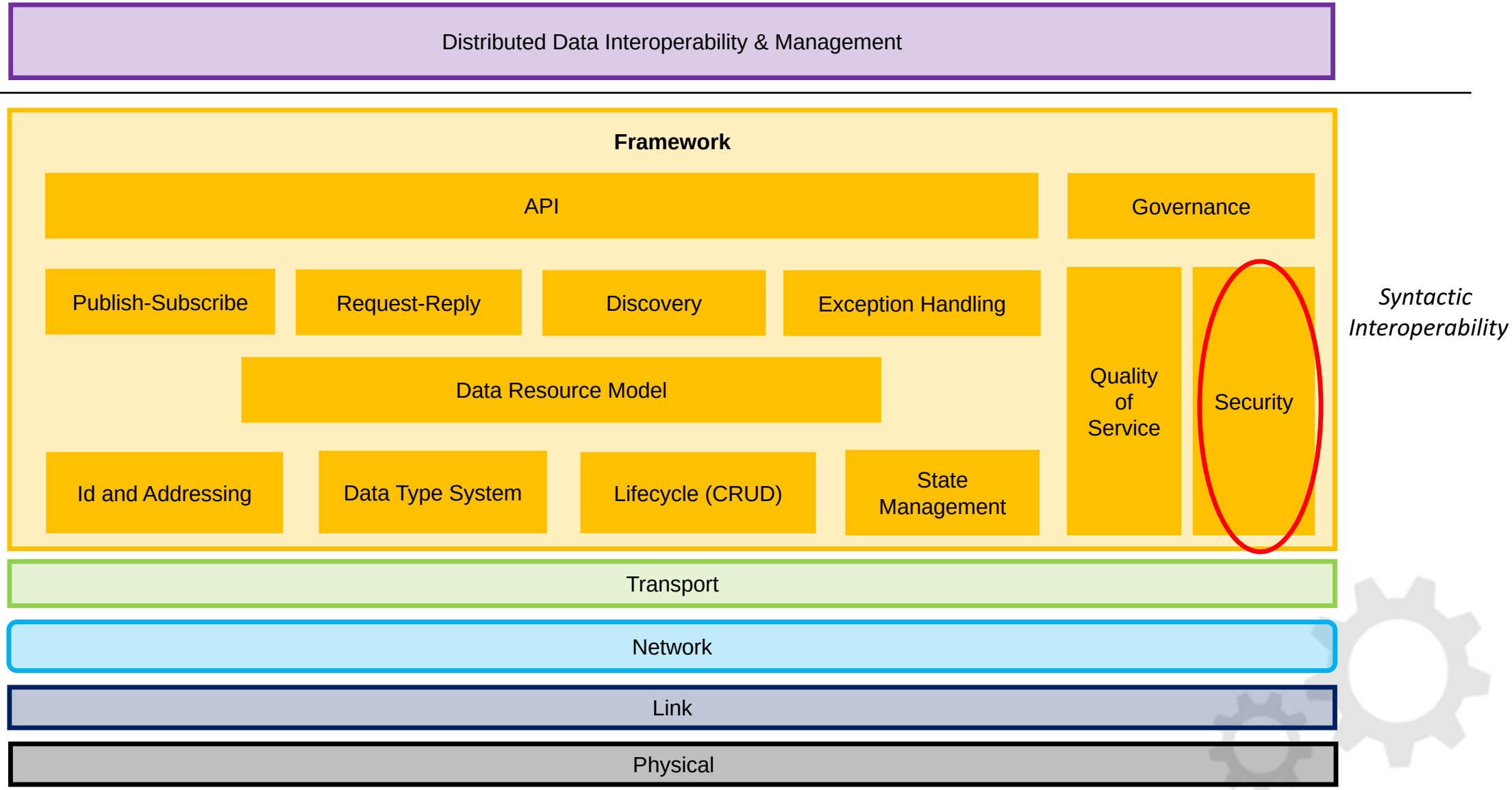
Connectivity Framework Layer



Connectivity Framework Functions

Syntactic Interoperability

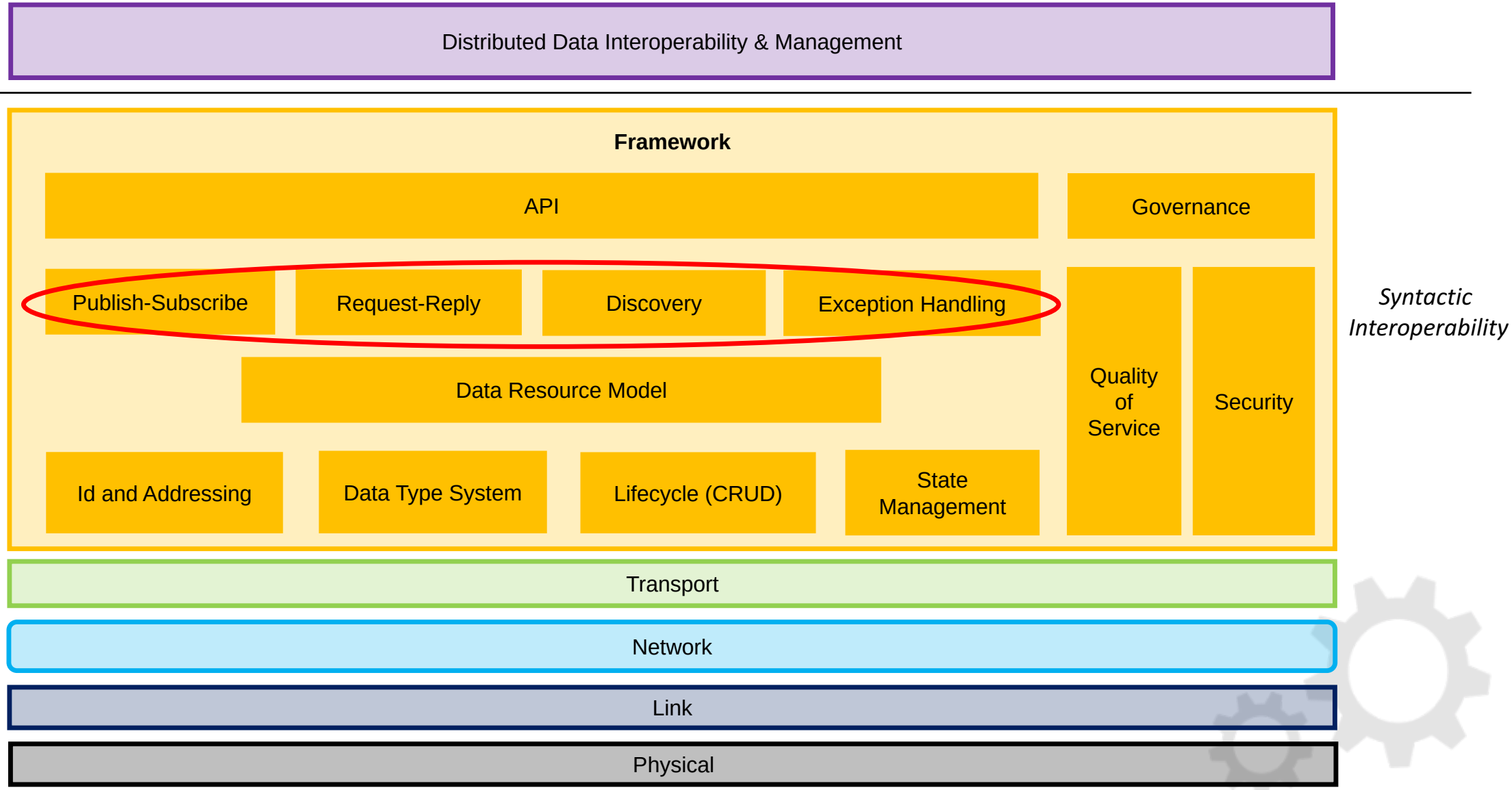
Connectivity Framework Layer



Connectivity Framework Functions

Syntactic Interoperability

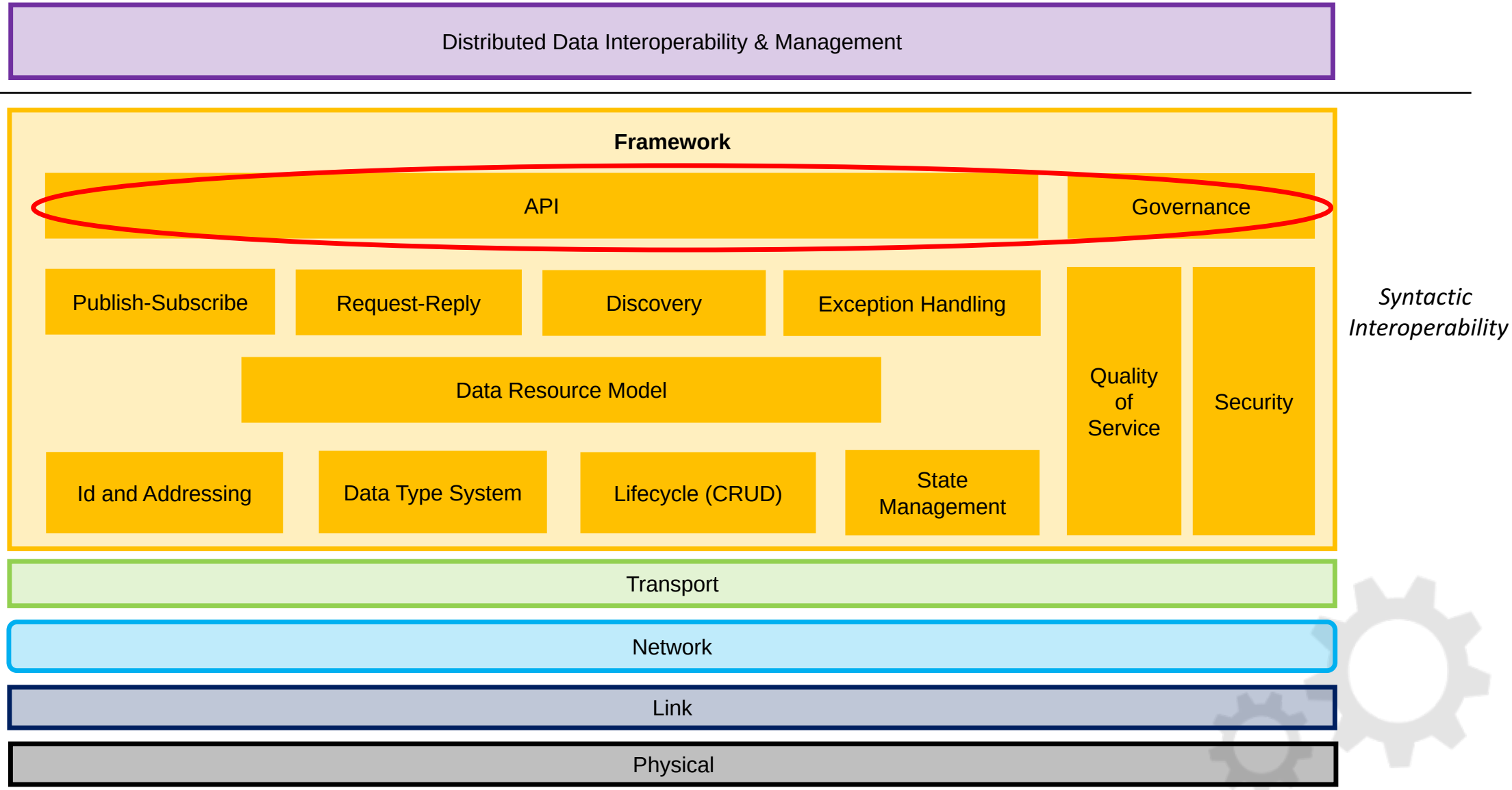
Connectivity Framework Layer



Connectivity Framework Functions

Syntactic Interoperability

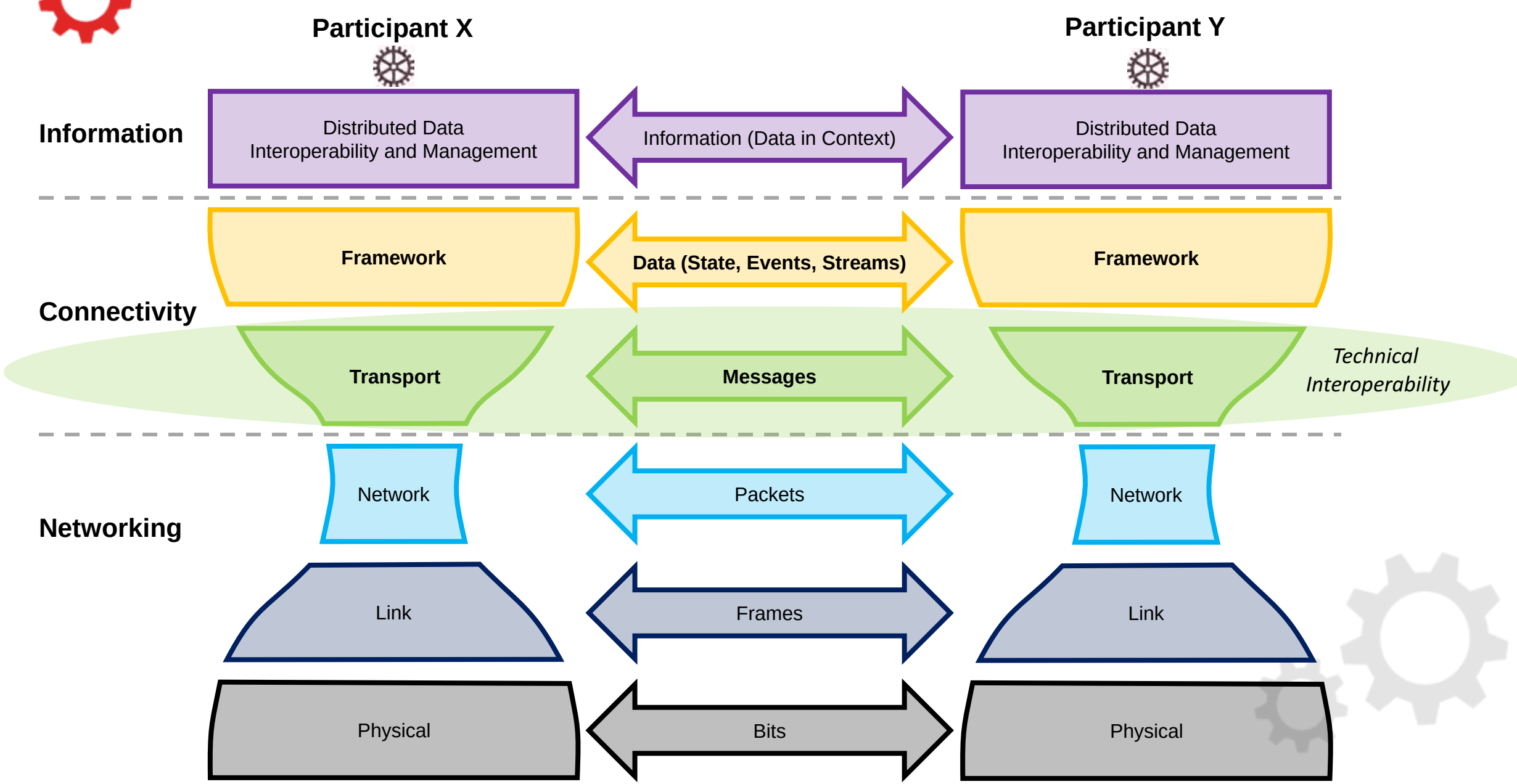
Connectivity Framework Layer



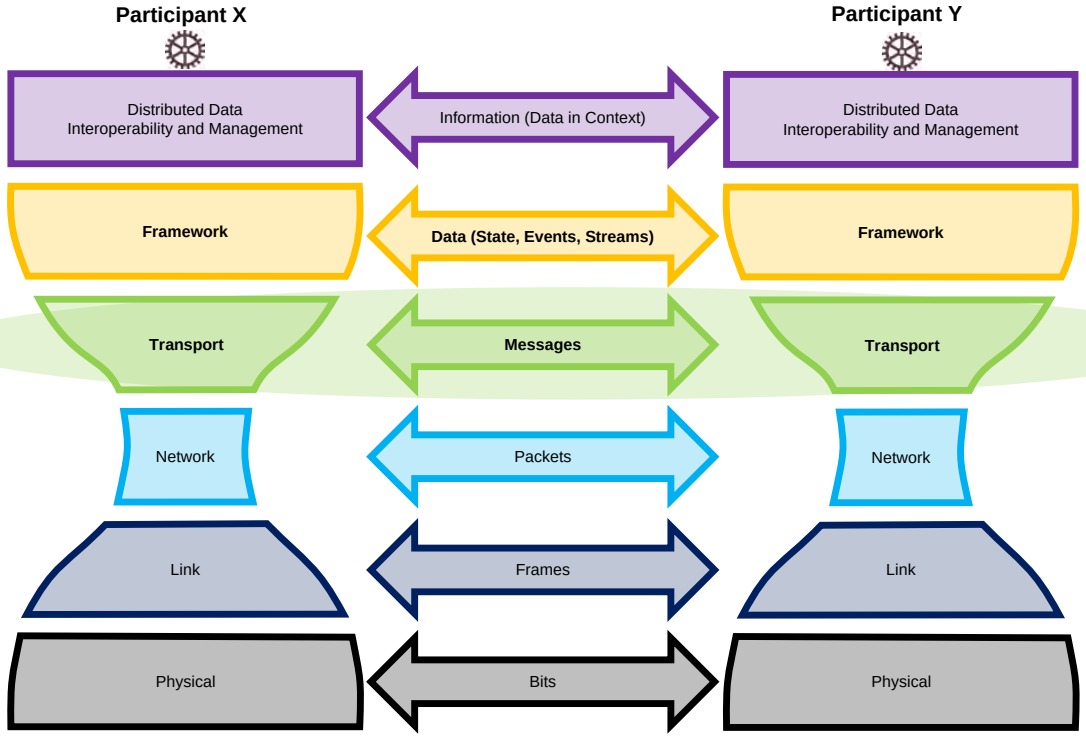
Connectivity Framework Functions

Syntactic Interoperability

IIoT Connectivity Stack



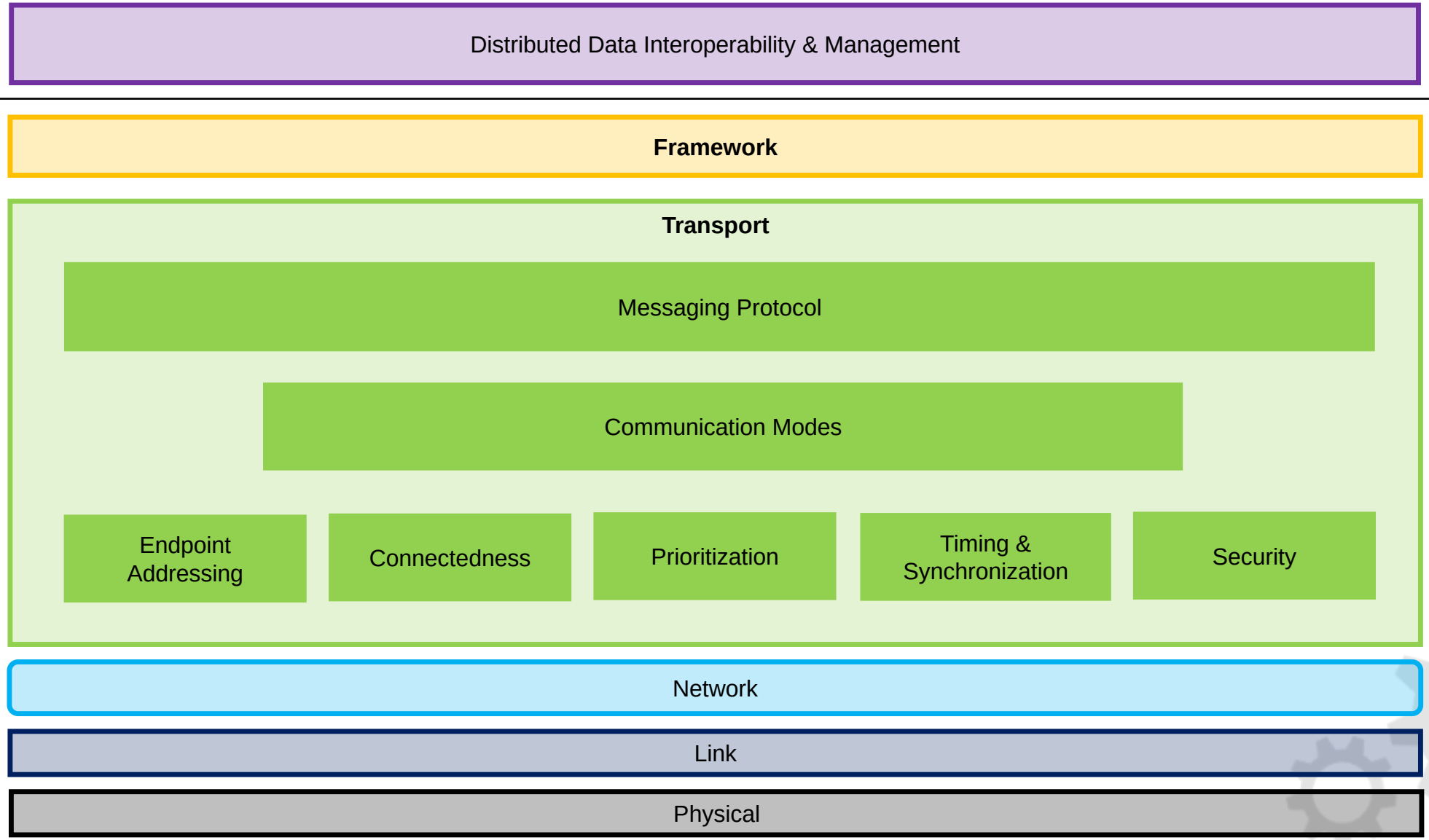
Transport Layer : Technical Interoperability



Connectivity Transport Layer

- Provides ***technical interoperability*** between endpoints
  - Share byte sequences
  - Structure (interpretation of bytes in context) is beyond the scope of this layer
- Connectivity Transport Layer Infrastructure
  - Any computing platform
  - May observe byte flows & optimize byte sequence sharing and delivery

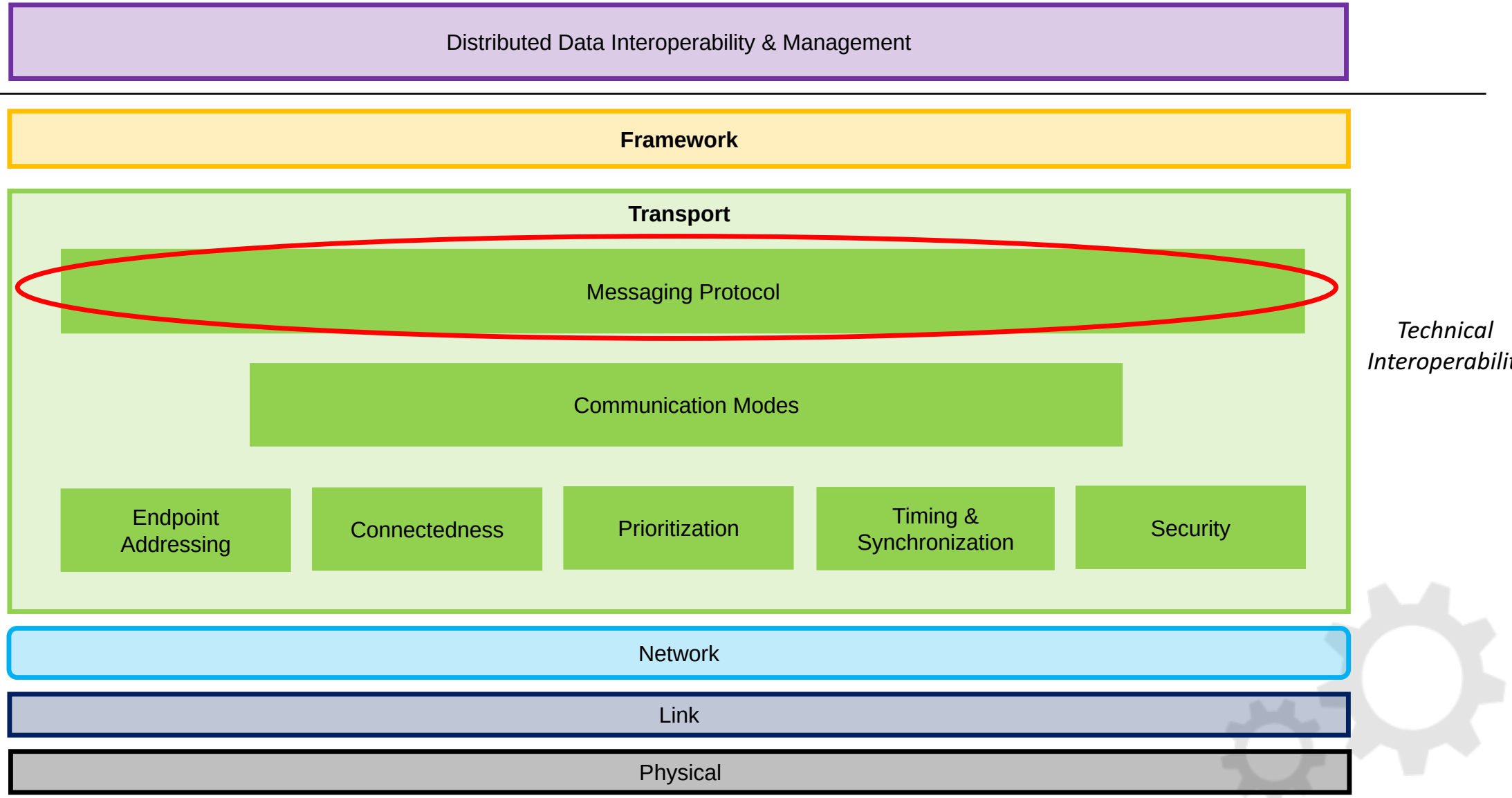
Connectivity Transport Layer



Connectivity Transport Functions

Technical Interoperability

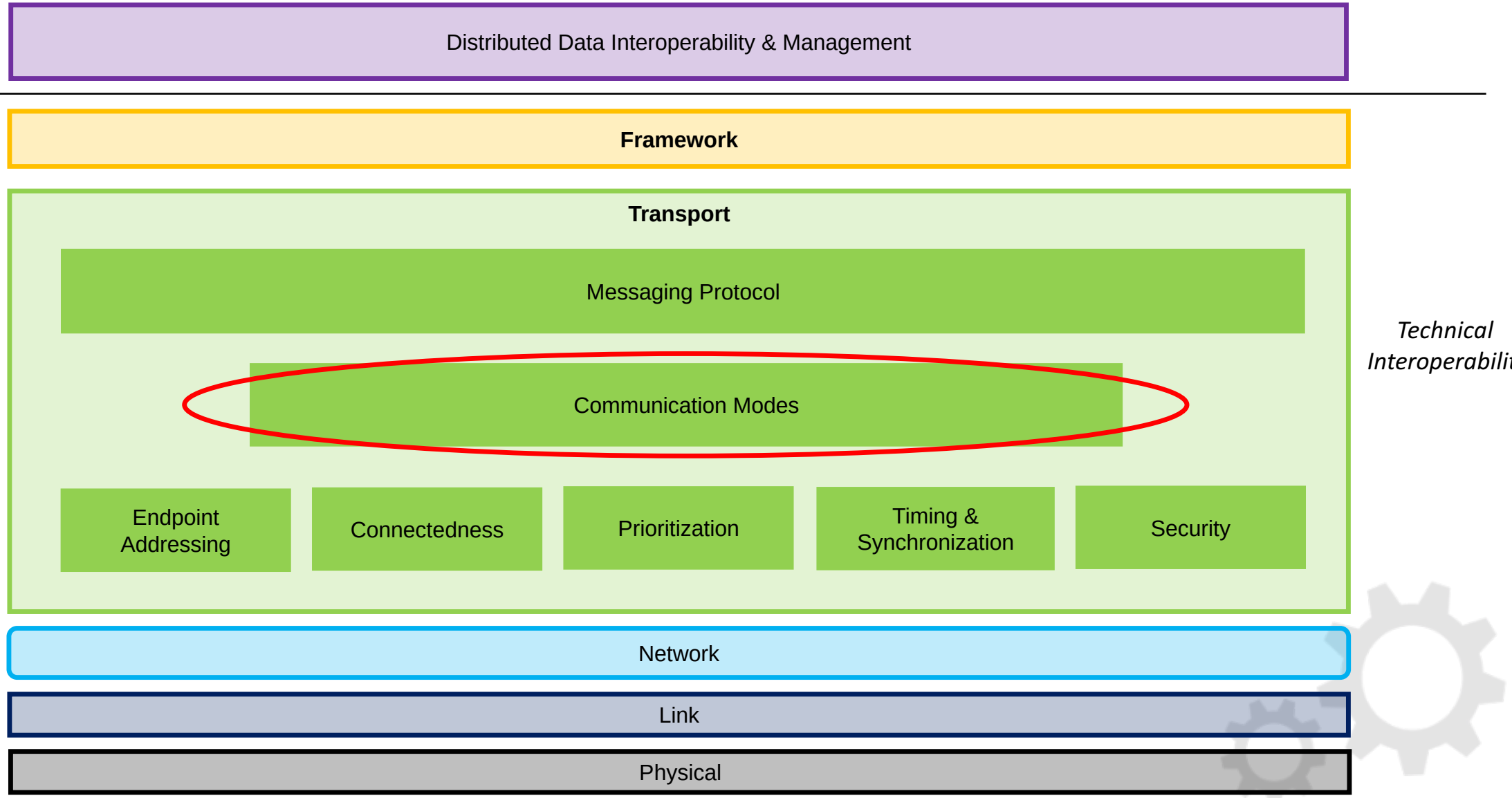
Connectivity Transport Layer



Connectivity Transport Functions

Technical Interoperability

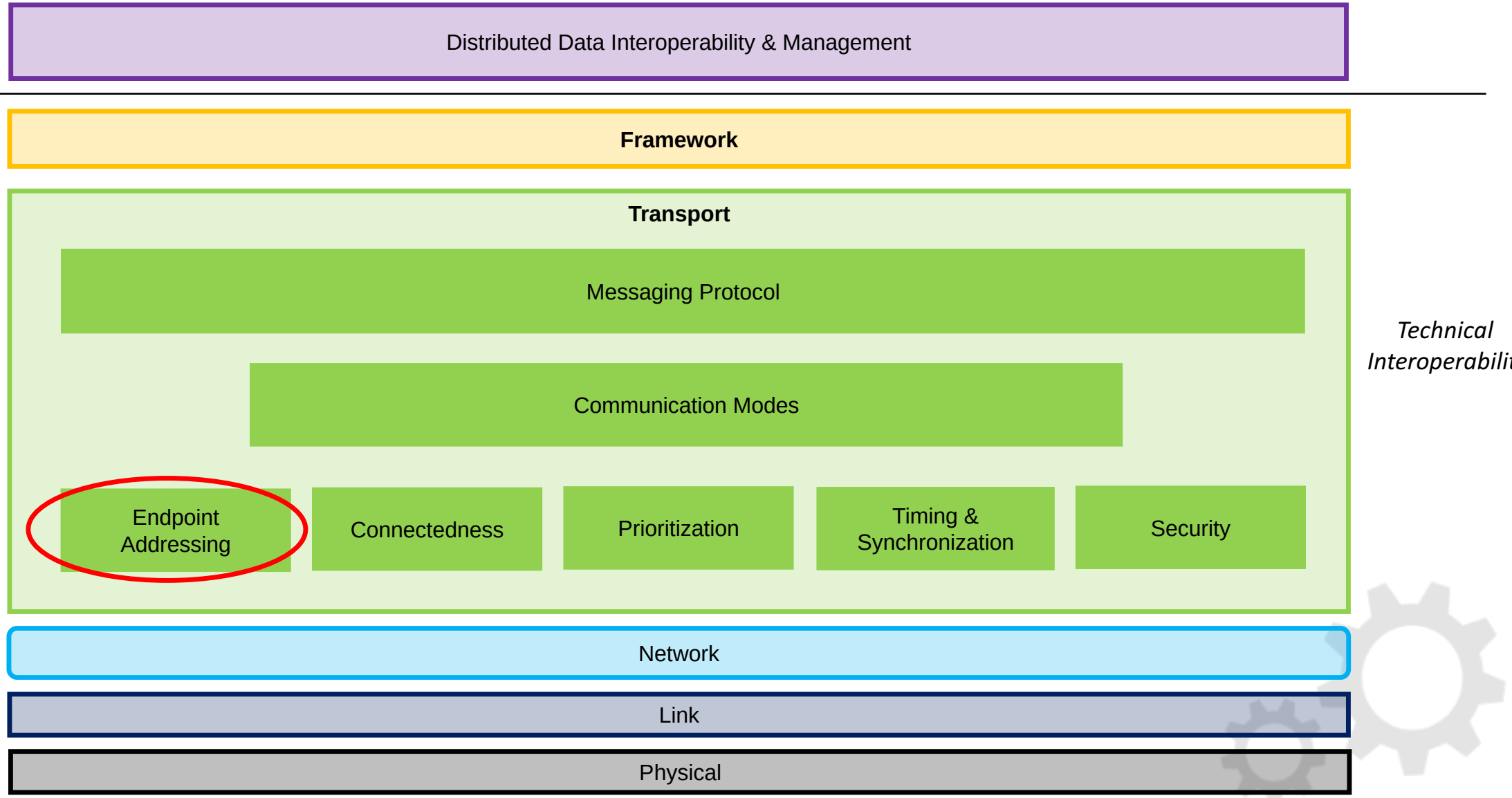
Connectivity Transport Layer



Connectivity Transport Functions

Technical Interoperability

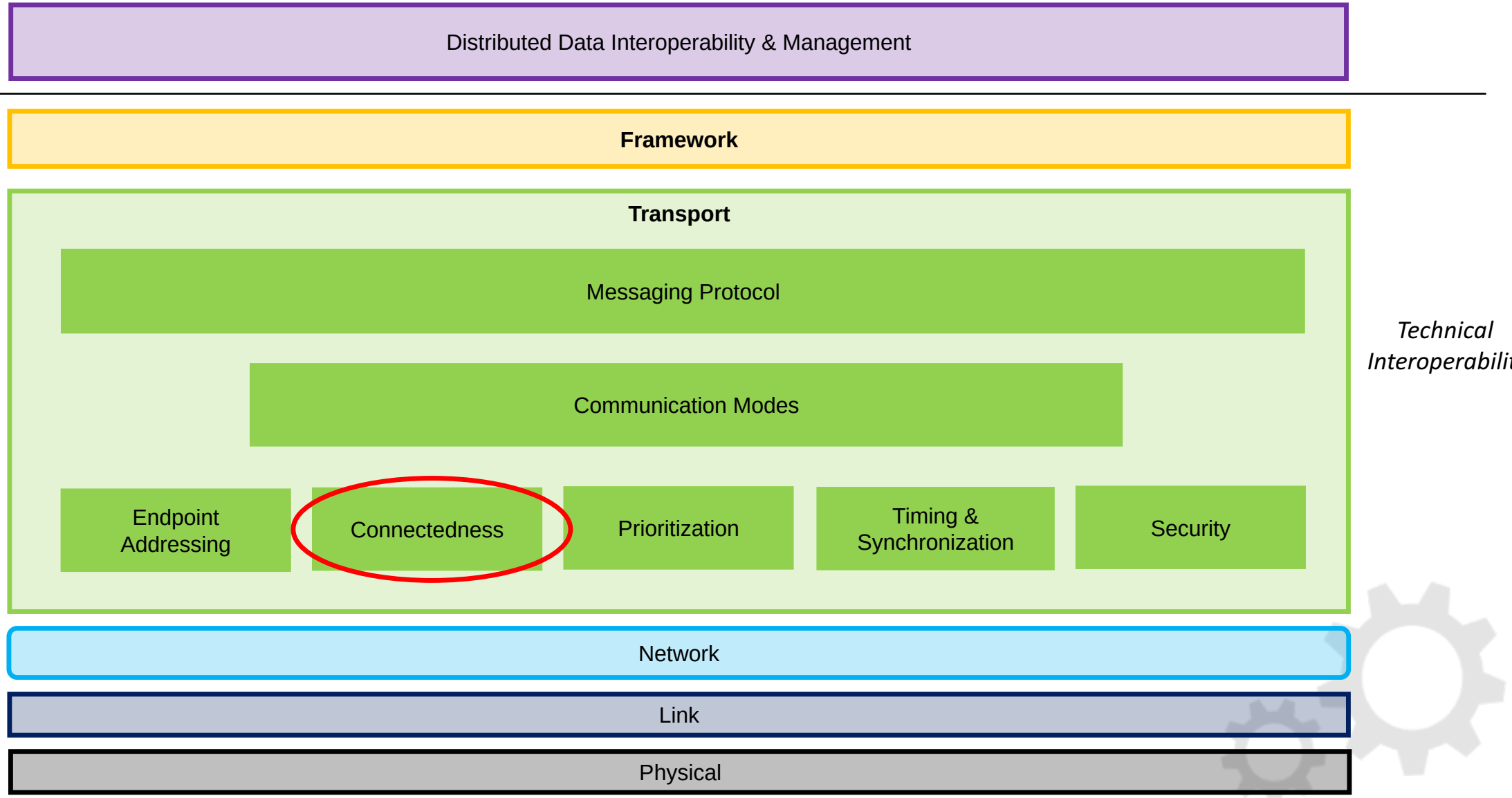
Connectivity Transport Layer



Connectivity Transport Functions

Technical Interoperability

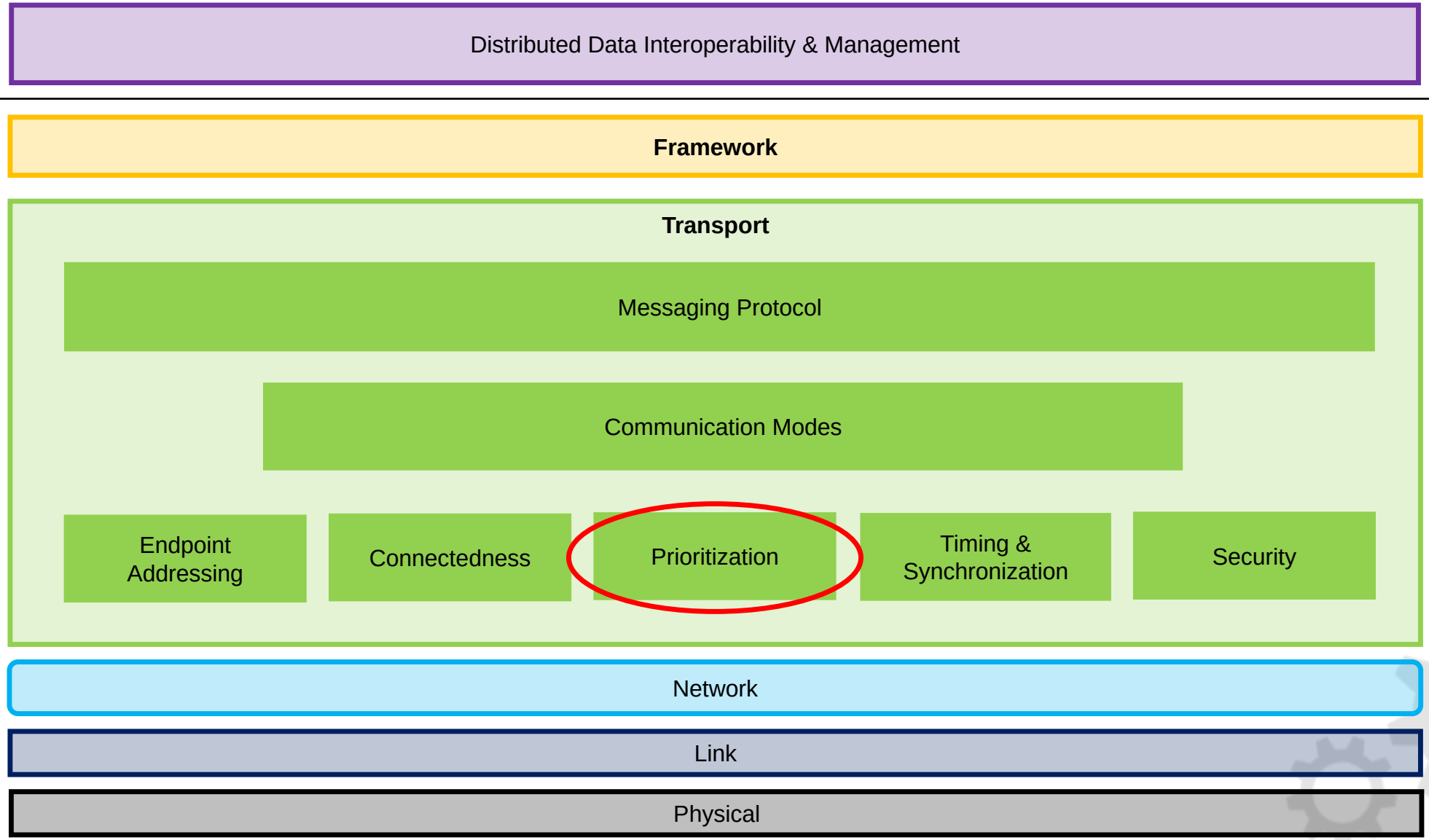
Connectivity Transport Layer



Connectivity Transport Functions

Technical Interoperability

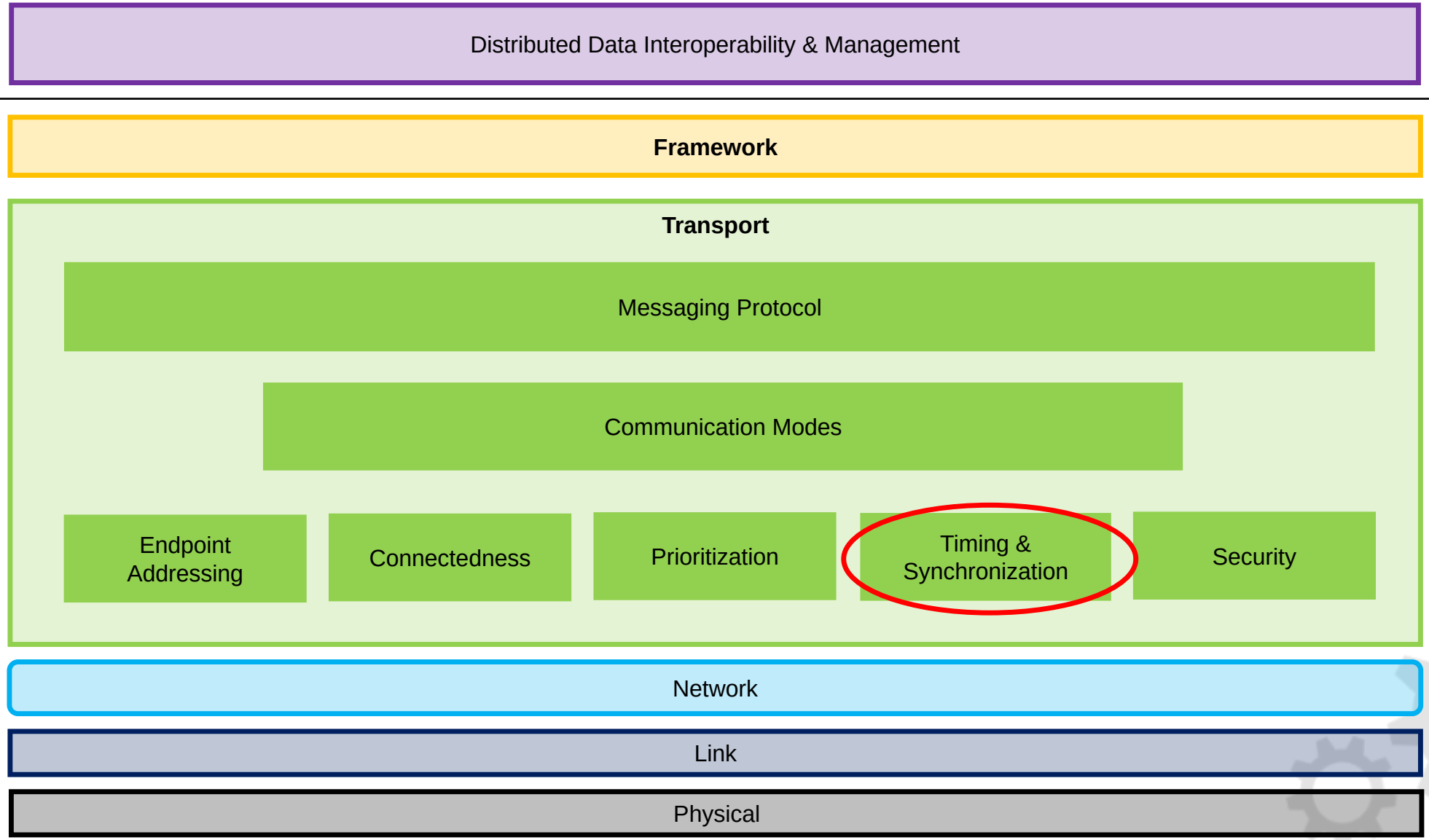
Connectivity Transport Layer



Connectivity Transport Functions

Technical Interoperability

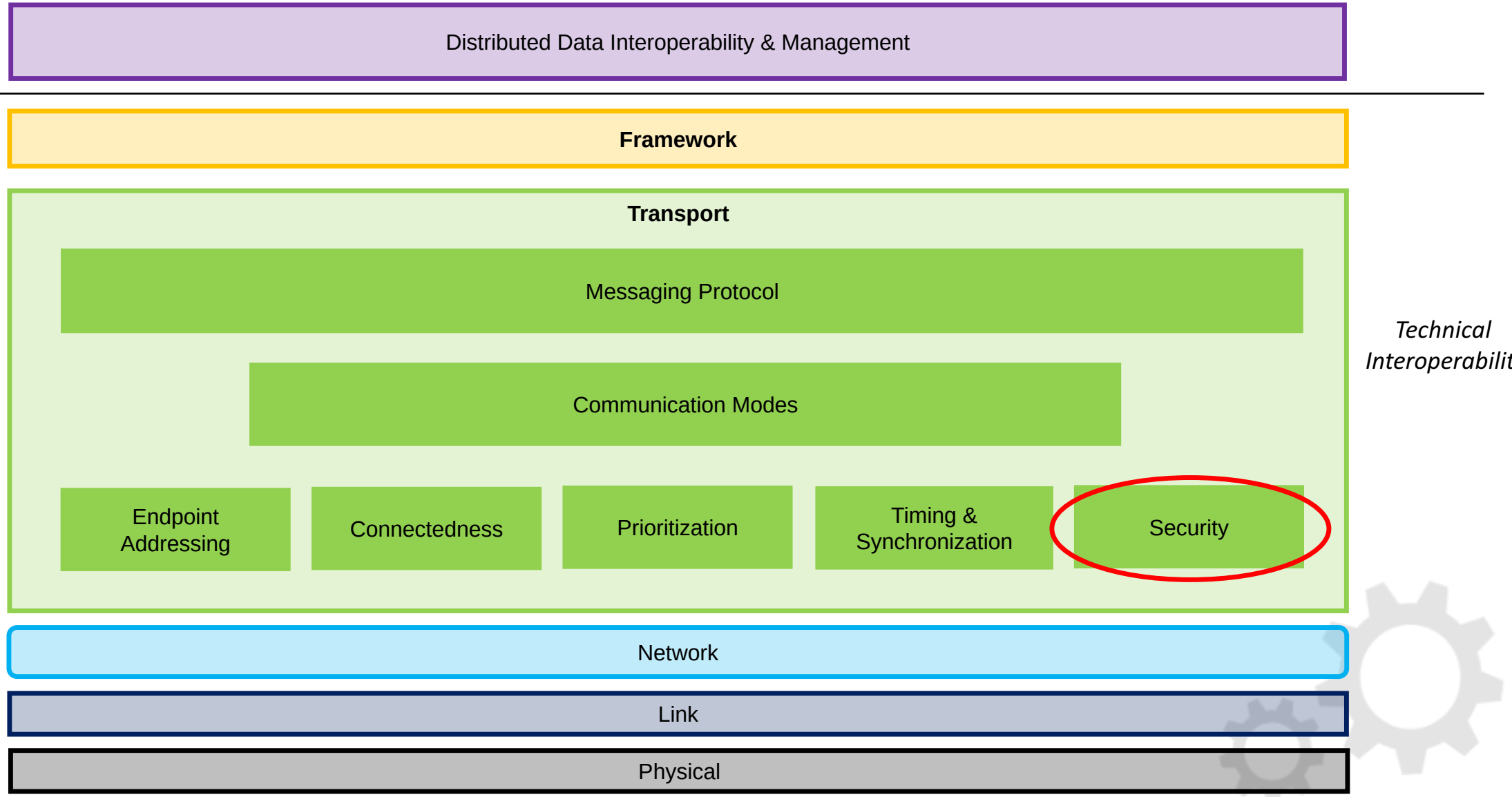
Connectivity Transport Layer



Connectivity Transport Functions

Technical Interoperability

Connectivity Transport Layer



Connectivity Transport Functions

Technical Interoperability

Defining a long term stable IIoT architecture strategy

Embracing the old and the new

Connectivity core standards criteria

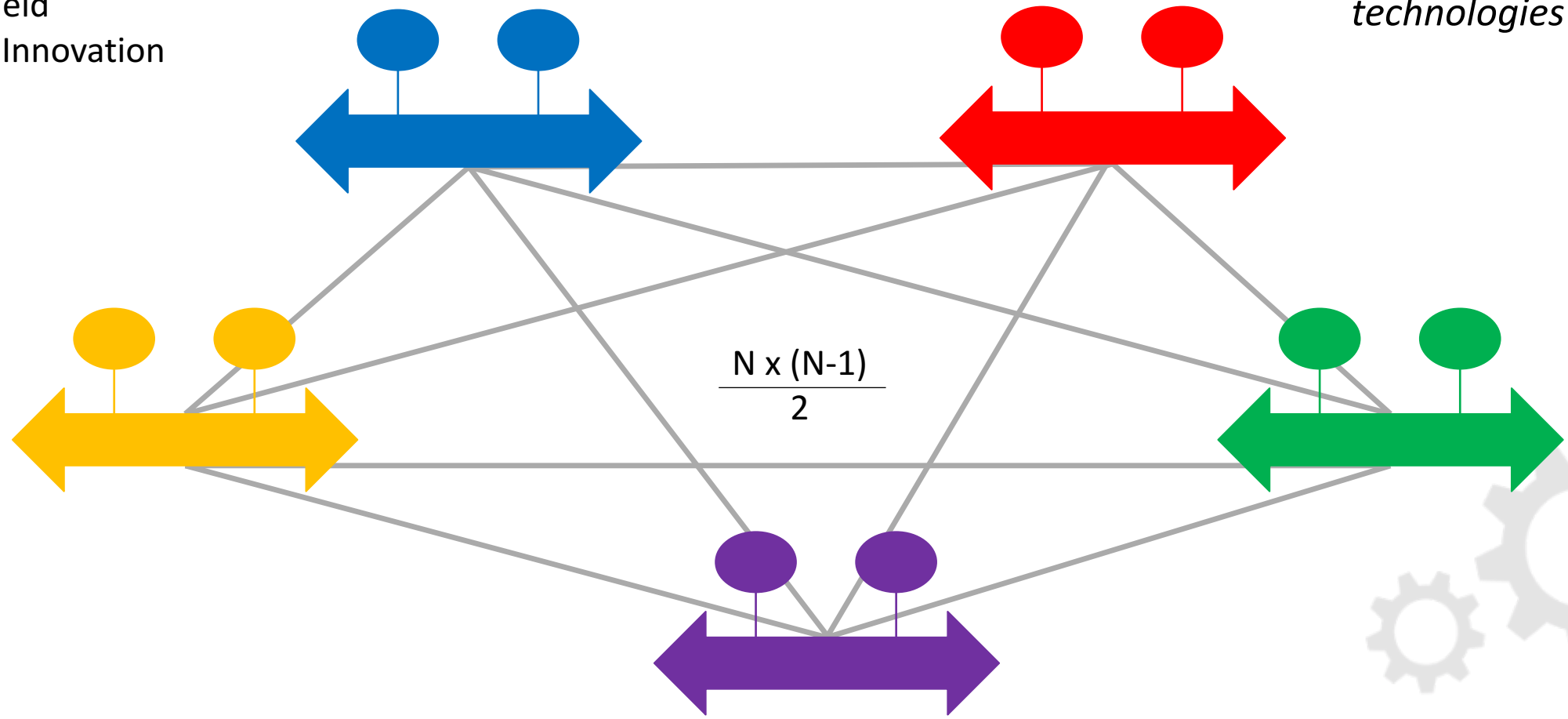
Fundamental N^2 Connectivity Challenge

- Brownfield
  - Existing technologies
  - May be specific to verticals
- Greenfield
  - Innovation

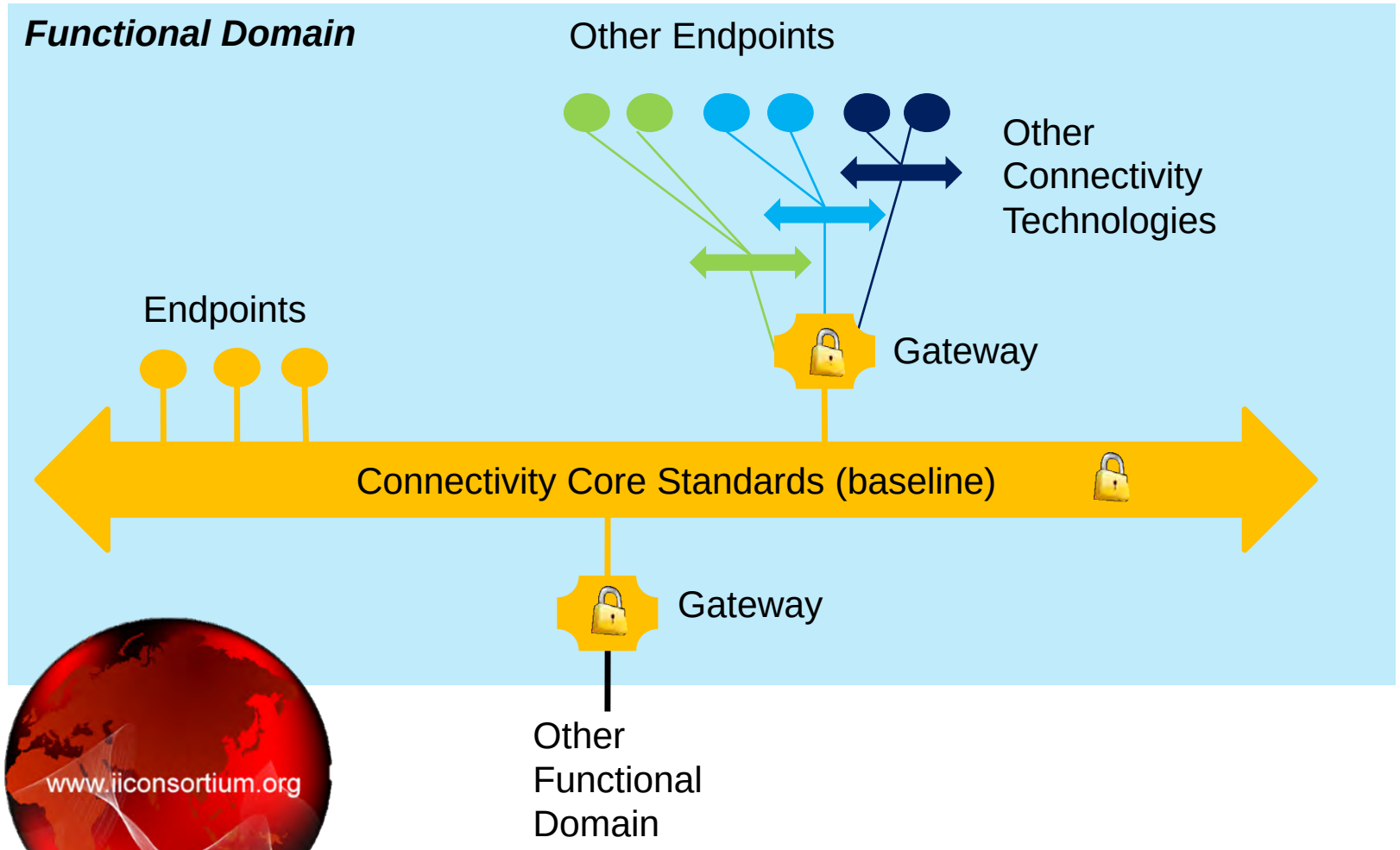
$O(N^2)$

Reality Check

Accept that there will be multiple connectivity technologies



Connectivity Reference Architecture



Gateways bridge to core connectivity standards:

- Delivers performance with flexibility
- Scales linearly (only have to map each “other” to one “core”)
- Supports dataflow security

Choose core standards that matches system needs

Connectivity Core Standards: “lingua franca” for IIoT interoperability

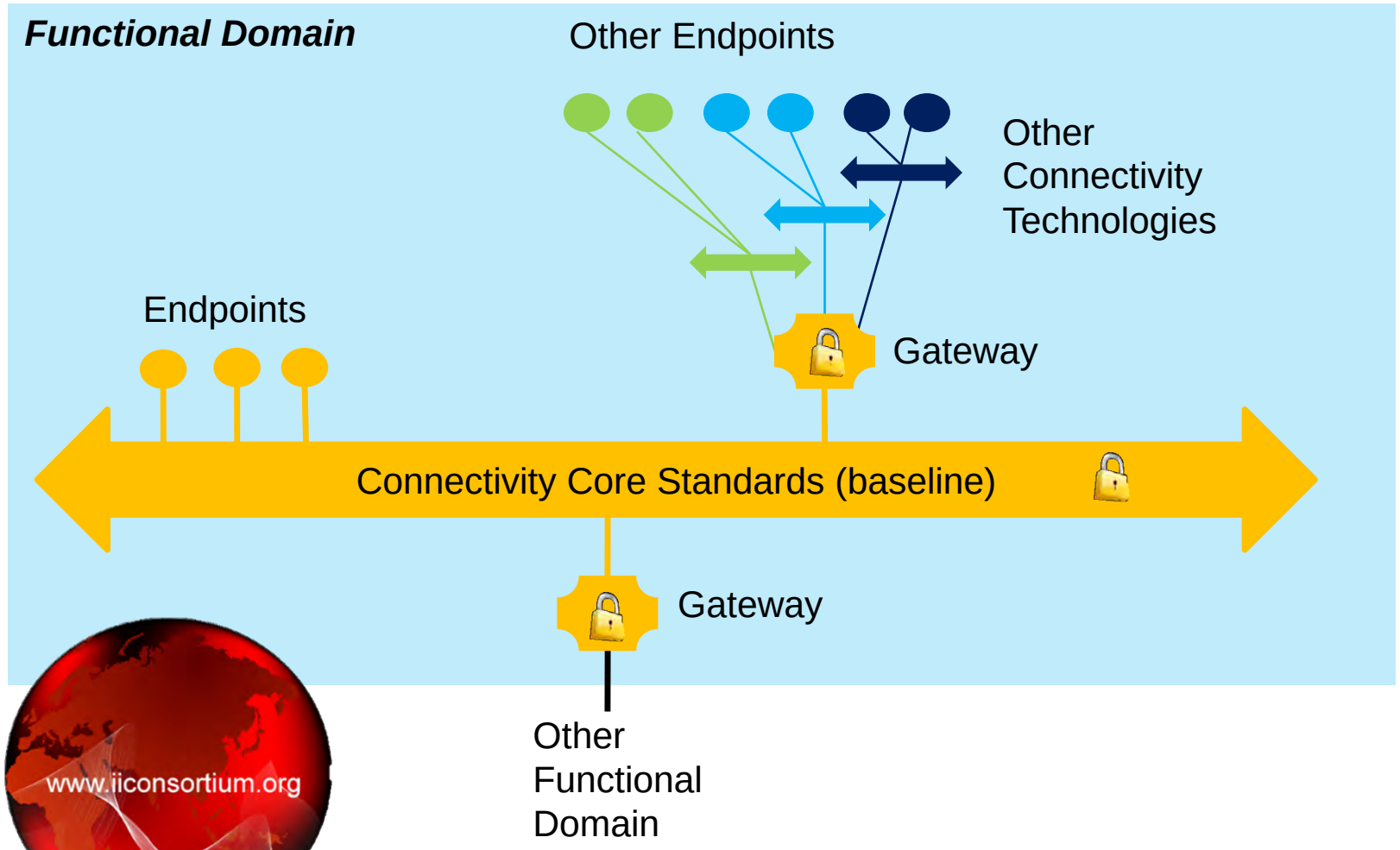
lin·gua fran·ca

/ˌliNGgwə ˈfraNGkə/

noun: ***lingua franca****; plural noun:* ***lingua francas***

a language that is adopted as a common language between speakers whose native languages are different

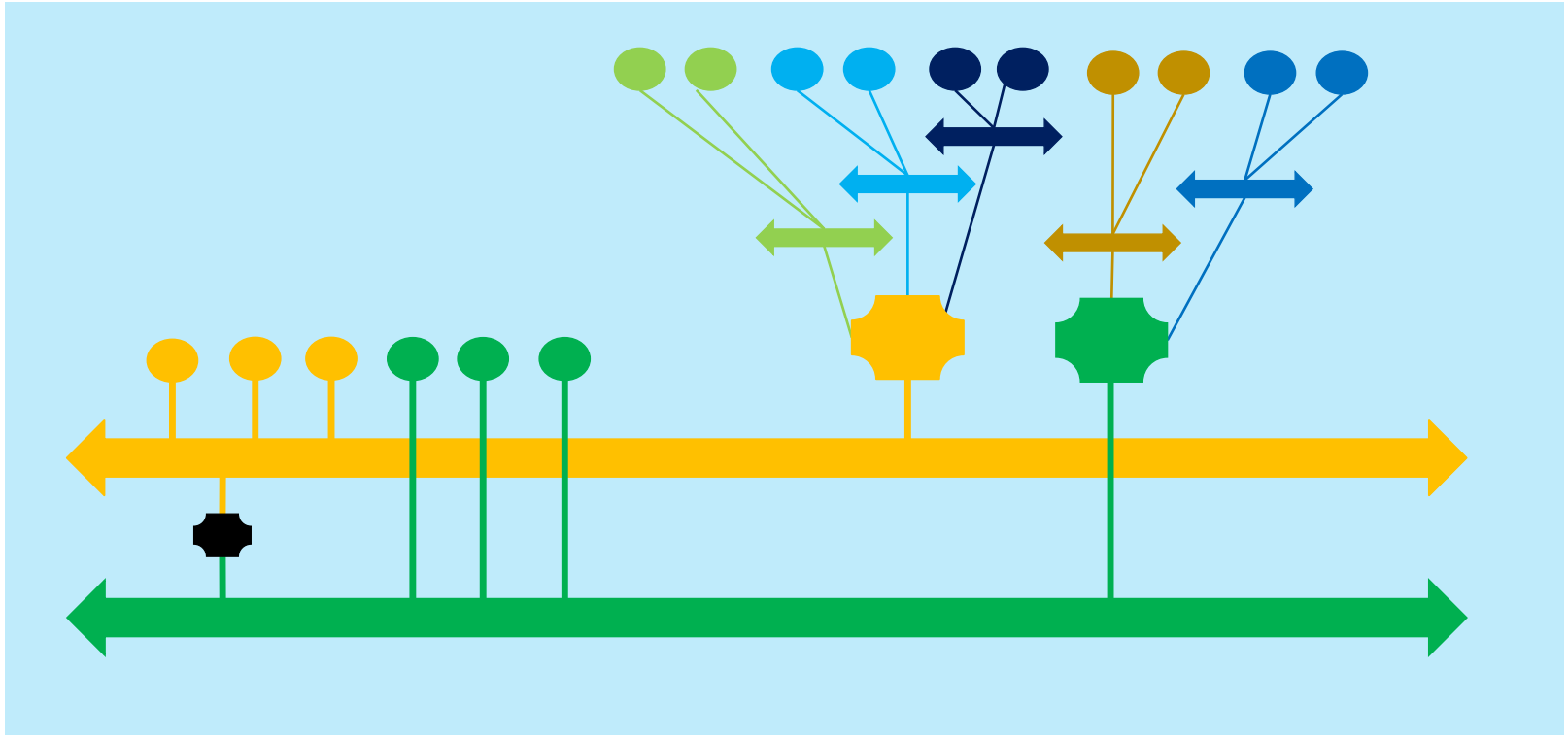
Connectivity Reference Architecture



Must not compromise:

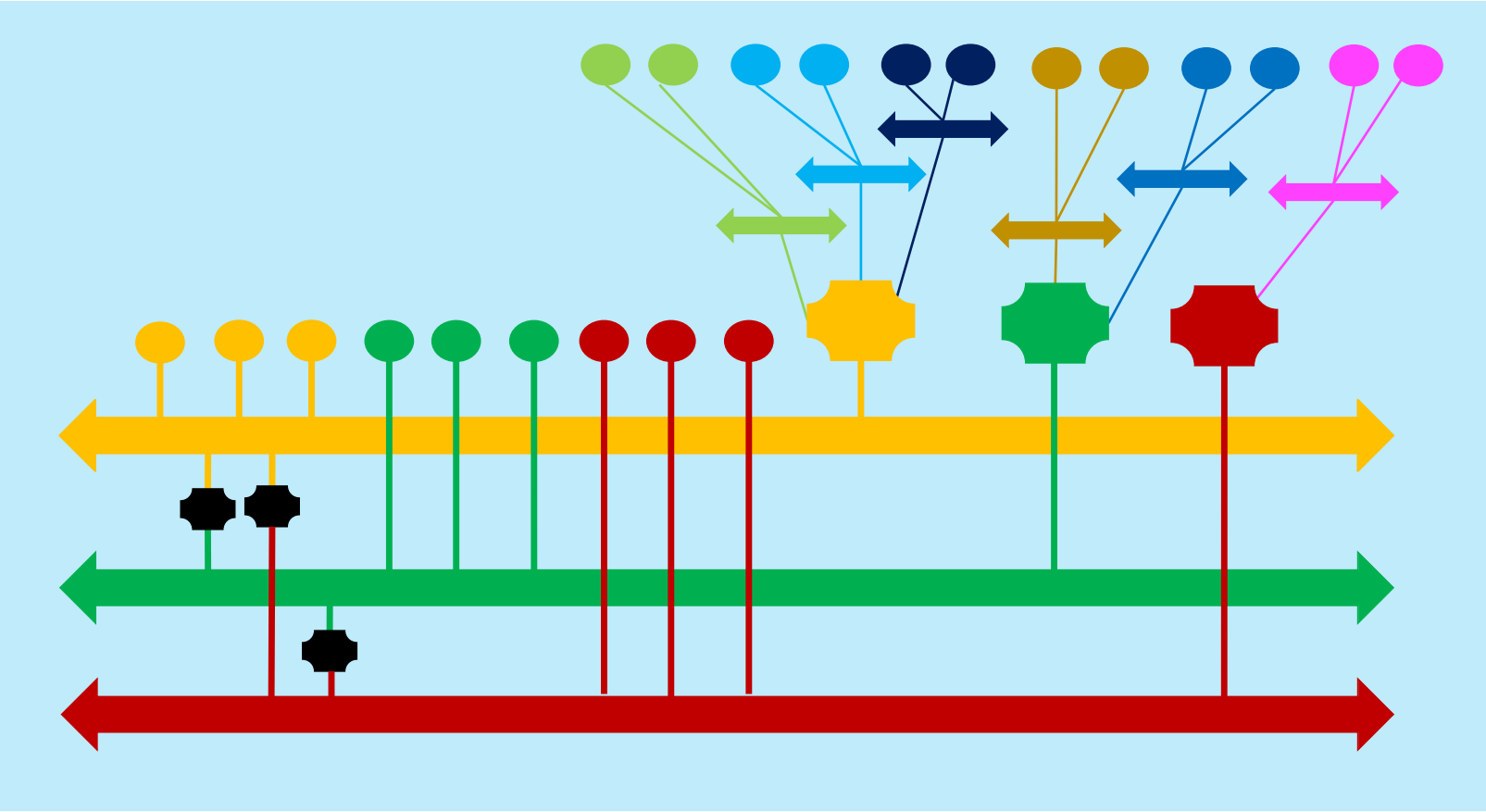
- Syntactic Interoperability
- Functional Requirements
- Non Functional Requirements
  - Performance
  - Scalability
  - Reliability
  - Resilience
  - Security
  - Safety

Core Gateway Standards between Core Connectivity Standards



Core Gateways enable Horizontal Interoperability

Few Core, Many Domain-Specific Standards

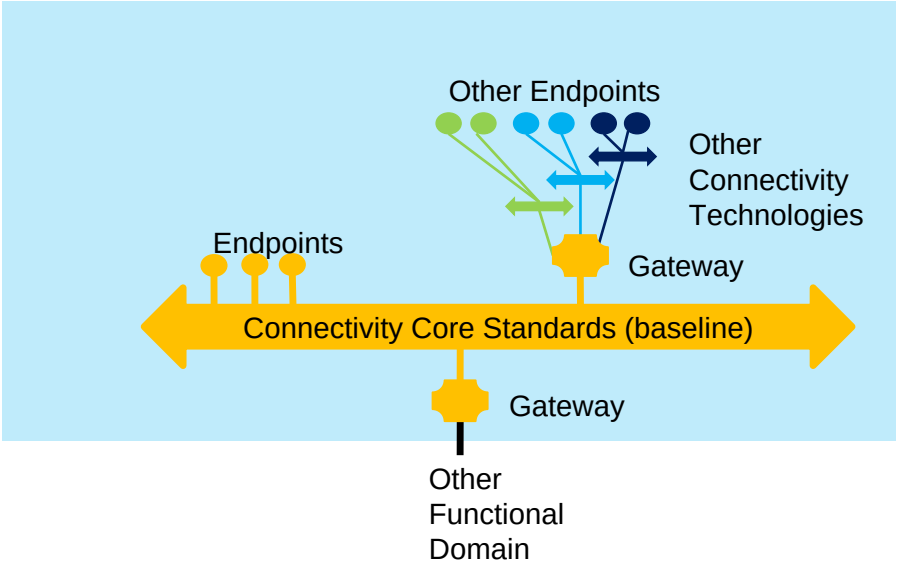


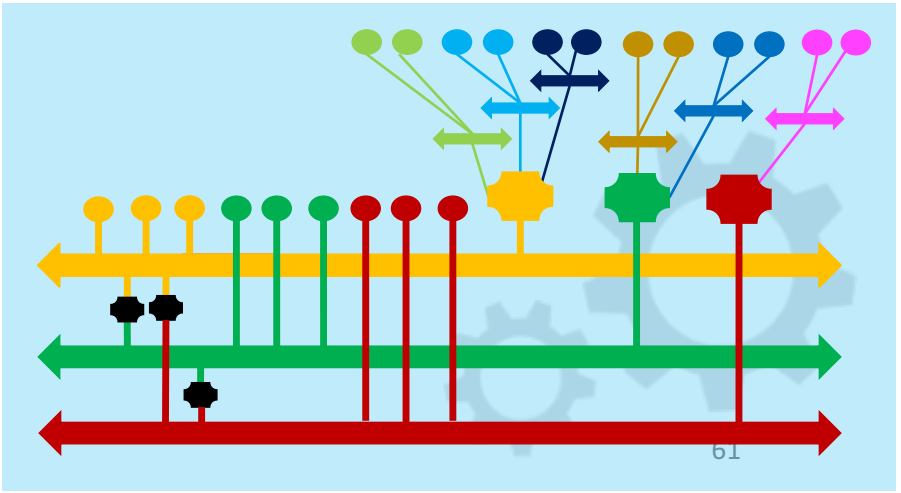
- Many Domain-Specific Connectivity Technologies
  - Common or de-facto connectivity technology or standard for a relevant industry or functional domain
  - Gateway will be needed to one of the core connectivity standards
  - Lots of these!
- Few Connectivity Core Standards
  - K Core Connectivity Standards
    - $K*(K-1)/2 + (N-K)$
    - when $K << N$, $O(N^2)$ → **O(N)**
  - Must meet the *Connectivity Core Standards Criteria*

Connectivity Core Standards Criteria

		Core Standard Criterion
Definition	1	Provide **syntactic interoperability**
	2	Open standard with strong **independent, international** governance
	3	**Horizontal** and neutral in its applicability across industries
	4	**Stable** and **deployed** across multiple vertical industries
	5	Have **standards-defined *Core Gateways*** to *all* other core connectivity standards
Technical	6	Meet the connectivity framework **functional** requirements
	7	Meet **non-functional** requirements of performance, scalability, reliability, resilience
	8	Meet **security** and safety requirements
Business	9	Not require any single component from any single vendor
	10	Have readily-available SDKs both **commercial** and **open source**

GREEN = Gating Criteria



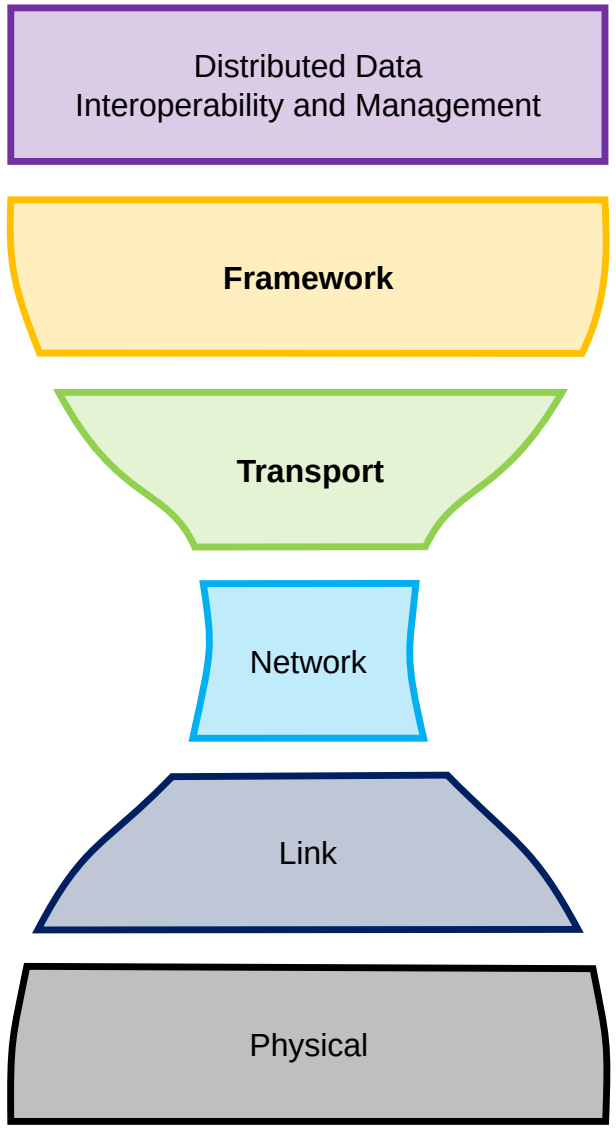


Selecting the right connectivity technology

Assessment Template Worksheets

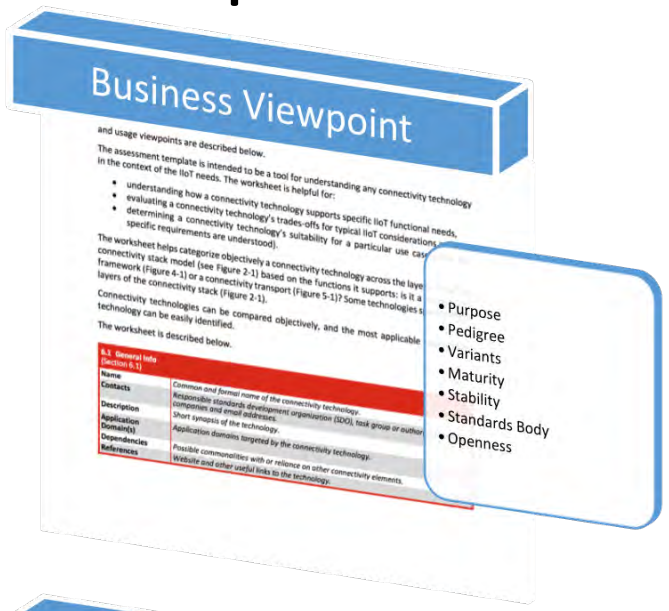
Connectivity Standards

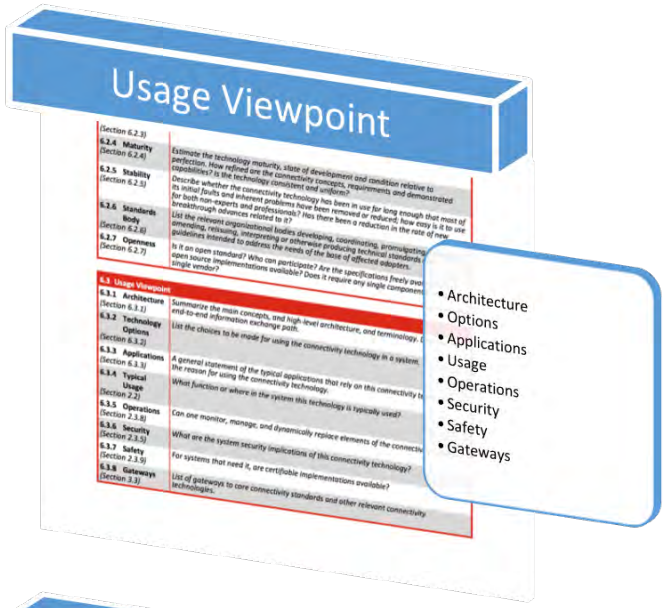
Assessment Template

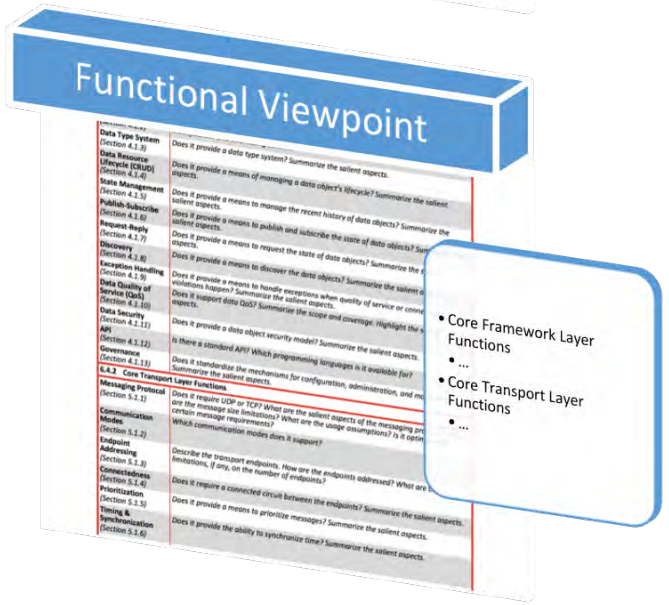


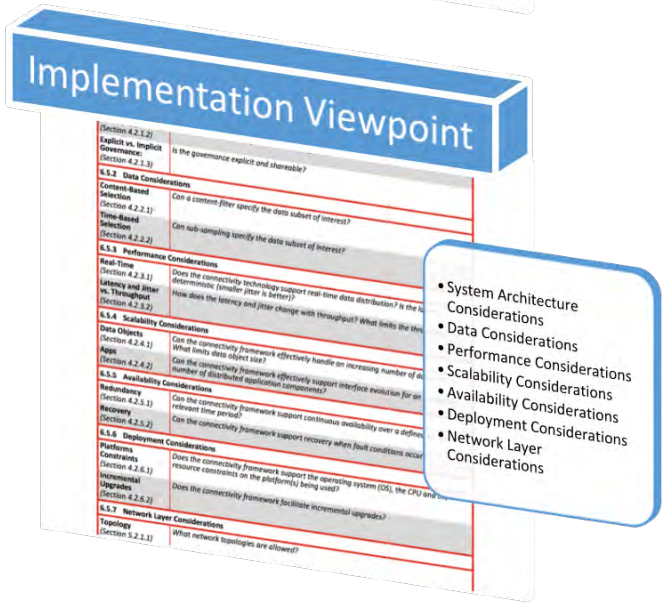
- Which layers(s) of the **Connectivity Stack** does it provide?
  - May span multiple layers
- What **Core Functions** does it provide?
  - Prioritize the functions for your use case
- How does it rank against the **Typical Considerations** (of the layers spanned) ?
  - Prioritize the considerations for your use case
- How does it impact system **Architectural Qualities**?
  - Prioritize the qualities for your use case
- How does it fit **Core Connectivity Criteria**?
  - Is a gateway to a Core Connectivity Standard available?
  - Is the gateway standardized?

Assessment Template Worksheets

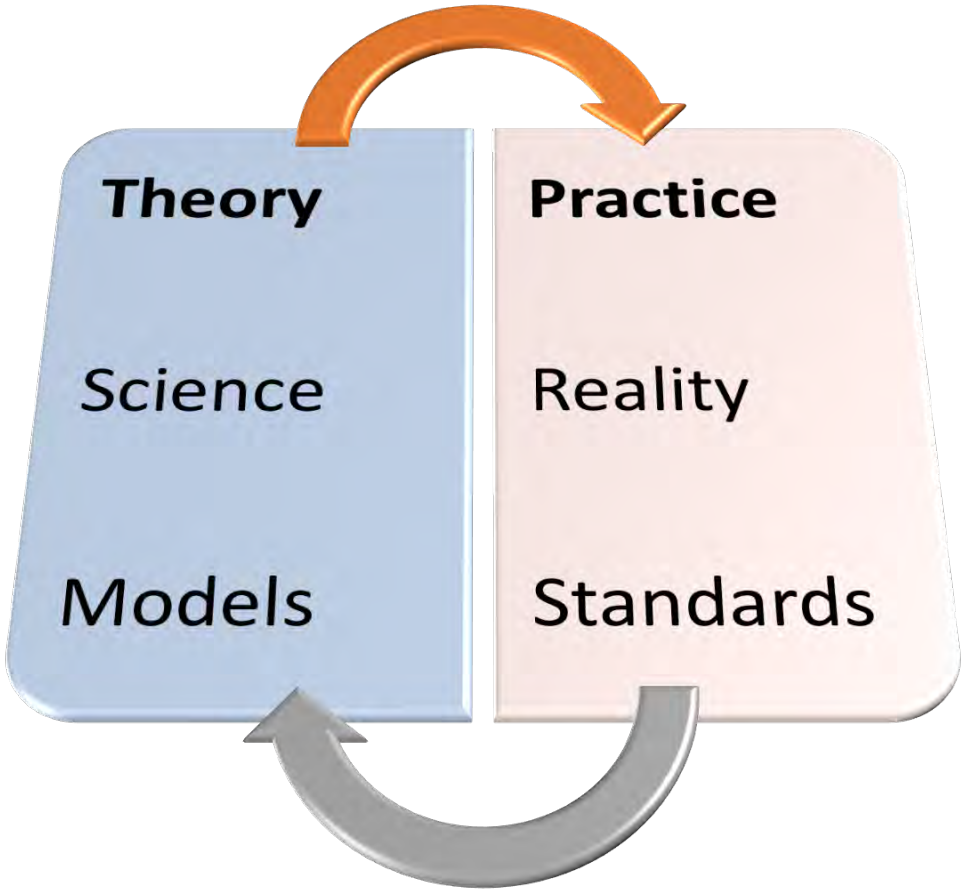








Theory meets Practice!



Relevant Connectivity Standards

…

Energy & Utilities

Healthcare

Manufacturing

Transportation

…

Distributed Data Interoperability and Management

Framework

Transport

Network

Link

Physical

Telecommunications Origin

Manufacturing Origin

DDS

oneM2M

Web Services

OPC-UA

DDSI-RTPS

CoAP

MQTT

HTTP

OPC-UA Bin

TCP

UDP

TCP

Internet Protocol (IP)

TSN / Ethernet (802.1, 802.3)

Wireless PAN (802.15)

Wireless LAN (802.11 Wi-Fi)

Wireless 2G/3G/LTE (3GPP)

Wireless Wide Area (802.16)

Connectivity Core Standards Criteria Applied

	Core Standard Criterion	DDS	Web Services	OPC-UA	oneM2M
1	Provide **syntactic interoperability**	✔	Need XML or JSON	✔	✔
2	Open standard with strong **independent, international** governance	✔	✔	✔	✔
3	**Horizontal** and neutral in its applicability across industries	✔	✔	✔	✔
4	**Stable** and **deployed** across multiple vertical industries	Software Integration & Autonomy	✔	Manufacturing	Home Automation
5	Have **standards-defined *Core Gateways*** to *all* other core connectivity standards	Web Services, OPC-UA*, oneM2M*	DDS, OPC-UA, oneM2M	Web Services, DDS*, oneM2M*	Web Services, OPC-UA*, DDS*
6	Meet the connectivity framework **functional** requirements	✔	✘	Pub-Sub in development	✔
7	Meet **non-functional** requirements of performance, scalability, reliability, resilience	✔	✘	Real-time in development	Reports not yet documented or public
8	Meet **security** and safety requirements	✔	✔	✔	✔
9	Not require any single component from any single vendor	✔	✔	✔	✔
10	Have readily-available SDKs both **commercial** and **open source**	✔	✔	✔	✔

GREEN = Gating Criteria

* = work in progress

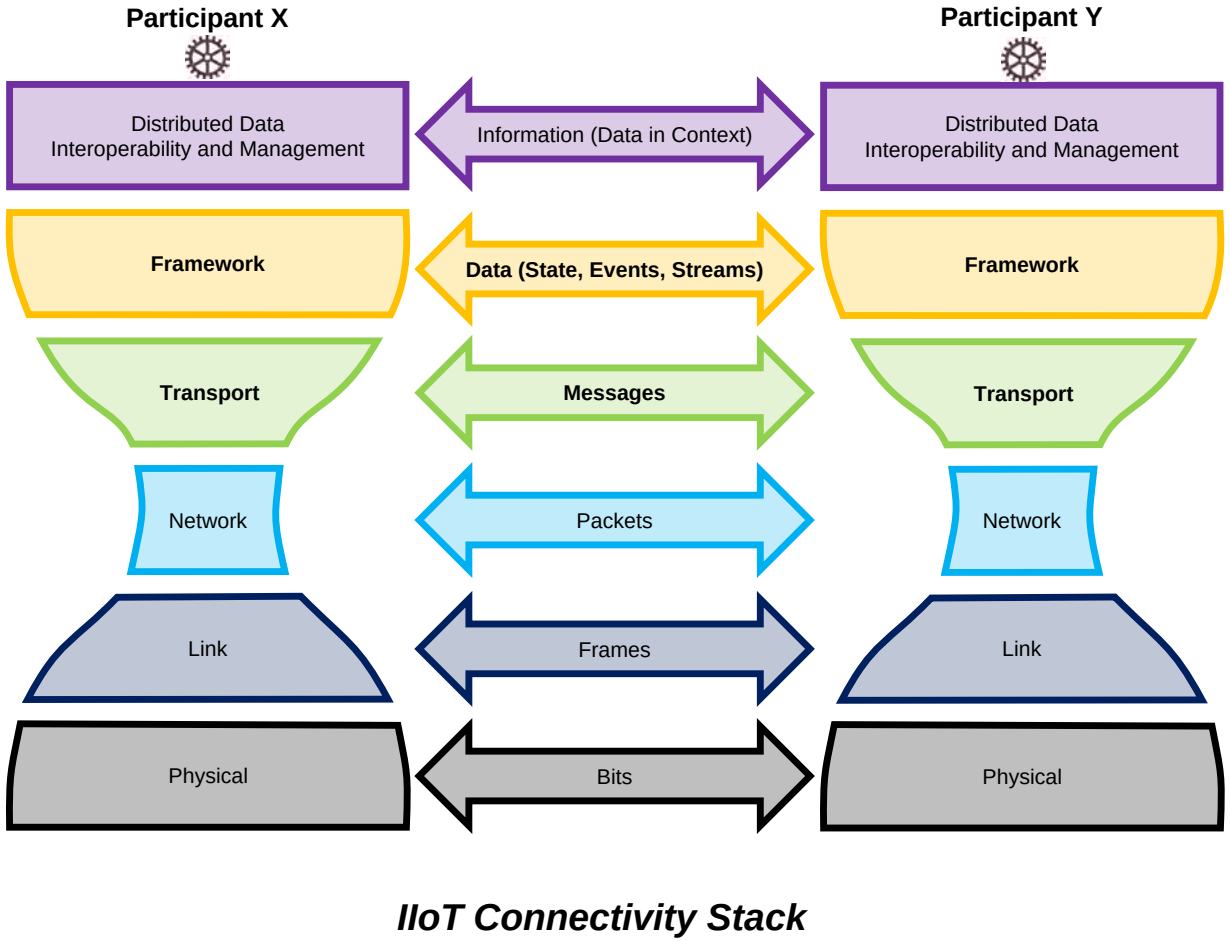
✓= supported, ✘ = **not** supported

Non-overlapping system aspect examples targeted by potential IIoT connectivity core standards

System Aspect	Example User	Approach	Targeting Standard
Software Integration and Autonomy	You are a software architect. You are building a system or product line, and you control the architecture. You critically need to integrate components written by different programmers or even entire teams.	A data centric approach will define the interfaces, capture the dataflow, enable module evolution, and enforce interoperation between teams. This approach also eases redundancy, fast complex data flow, and selective data filtering.	DDS
Device Interchangeability	You are a device manufacturer, with the goal of making devices that will sell into many applications. The device offers services, such as configure, start, stop, etc. You have no idea how the device will eventually be used. Your users are likely not software experts; they just want to add or integrate the device into a workcell.	A device-centric approach will allow the device users to write generic software that will interoperate with competitor's devices.	OPC-UA
Web and Mobile User Interfaces	You are building mobile apps or web browser based applications to provide the human machine interface. You need an easy way to support clean human interaction and access to backend services.	A RESTful approach will make it easy to connect to many types of enterprise systems and UI devices.	Web Services
Information & Communications Technology (ICT) Integration	You are building a wide-area wireless system that needs to allow applications and devices to share data and information. The devices use various technology and domain-specific protocols. The applications and devices you integrate rely on leveraging the services provided by the communications provider network.	A common, standard services-layer approach enables applications and device to share data and information without forcing the application to understand multiple protocols implemented on the devices. The applications can thus run in the Platform Tier and seamlessly connect to diverse IoT devices in the field.	oneM2M

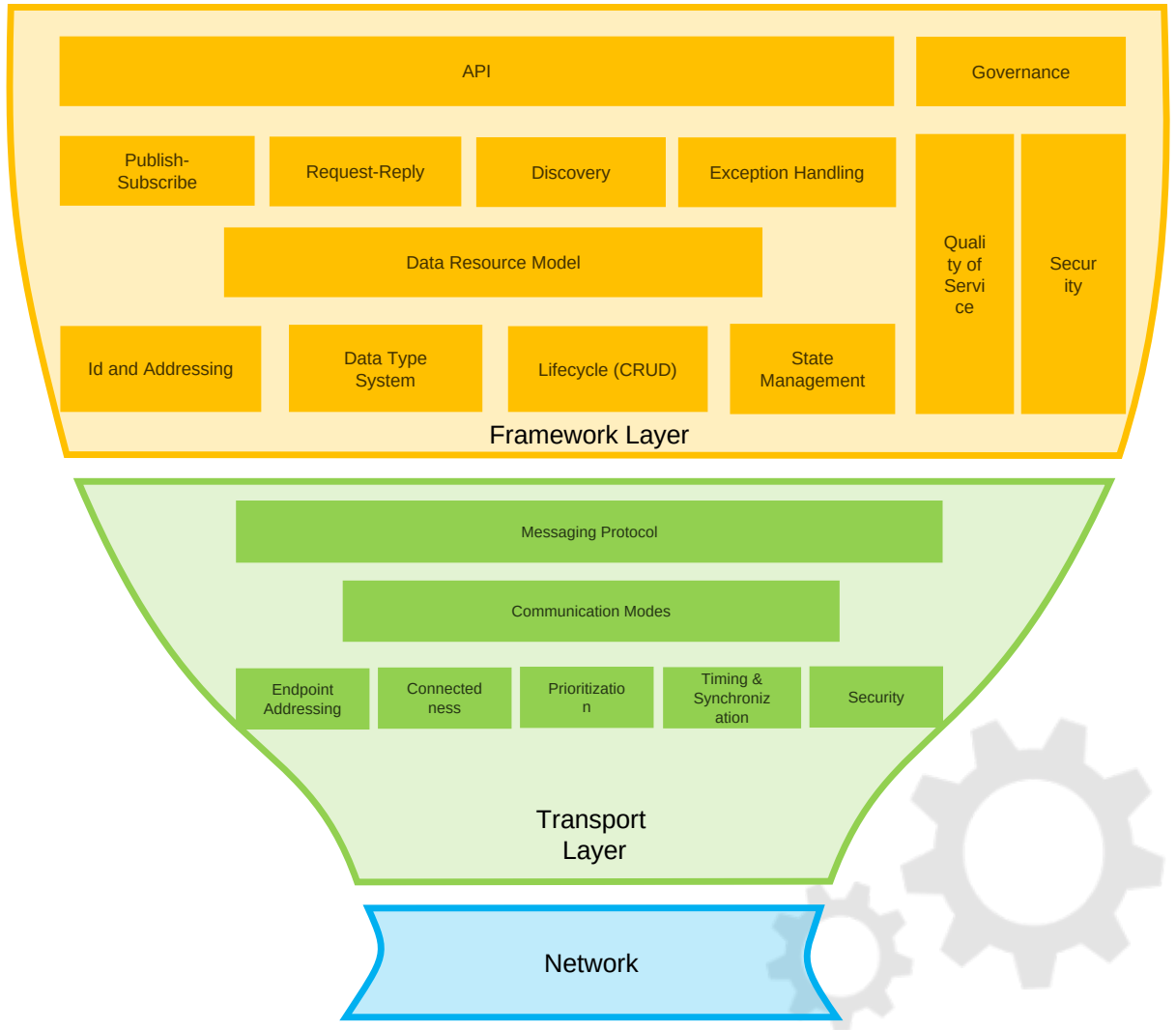
Summary

Industrial Internet Connectivity Framework (IICF)



IIoT Connectivity Stack

Syntactic Interoperability



Accelerate Your IIoT…

Guide map to the rich but often confusing landscape of IIoT connectivity

Clarity

✓ **Study the IICF**

Sets a stable long term foundation for IIoT interoperability

Foundation

✓ **Use the IICF**

Guidance

✓ **Build your IIoT**

Useful, practical, tangible guidance for requirements assessment, technology evaluation and selection

Get It!

FREE

1. Introduction
2. Connectivity Framework
3. Connectivity Reference Architecture
4. Connectivity Framework Layer
5. Connectivity Transport Layer
6. How to Assess a Connectivity Technology?
7. Connectivity Standards
8. Core Connectivity Standards
9. Other Connectivity Standards
10. Assessment Templates

https://www.iiconsortium.org/IICF.htm

DOWNLOAD PDF

IICF FAQ

Thank You!

Rajive Joshi, Ph. D.

Real-Time Innovations, Inc. (RTI)

rajive@rti.com