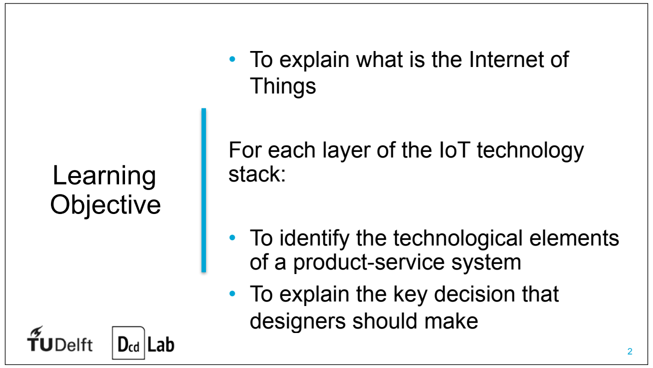
1

The Internet of Things, or the IoT, is the technology behind product-service systems. Like an iceberg, the physical 'Things' are the tip, visible above water while most of the technology and complexity is hidden, immersed under water.

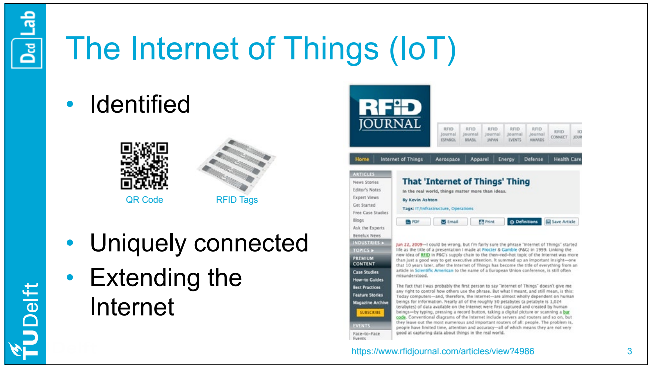
References:
- Alexander Hafemann on Unsplash: https://unsplash.com/@mlenny?utm_source=unsplash&utm_medium=referral&utm_content=creditCopyText



2

In this series of seven small videos, we will shed light on this digital technology, mapping its literacy through a layered framework so-called 'stack'.

We will explore what is the Internet of Things, extracting key roles of designers in the development of product-service systems.



3

To leverage a technology in design, it is important to understand what it is.

The Internet of Things would have been coined by Kevin Ashton in 1999. At least, that is what he describes in this RFID Journal article of 2009.

He recalls the 90s when Internet diagrams were including servers and routers, while missing the most important of the routers: us, people.

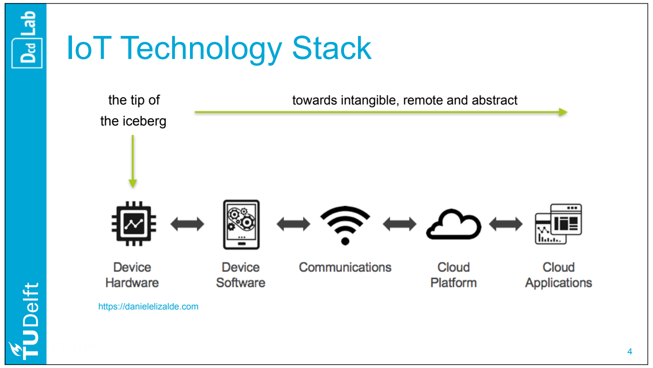
The Internet is about disseminating information but people have limited time, attention and accuracy. We are simply not good at capturing data about things in the real world.

Thus, the promise of the Internet of Things is about making us a bit super humans, helping us capturing data from the real world onto the Internet.

To do so, there are three key elements:

- First, physical things are identified on the internet, via various technologies such as RFID tags that we can find in clothing or QR Codes
- Second, a Thing refers to any physical object attached to a unique device that can connect as well as send and receive data through the Internet
- Finally, the IoT extend the Internet, a global end-to-end communication infrastructure

References:



4

The term ‘stack’ is common when referring to a framework describing technologies with multiple layers.

There are several ways to map the IoT technology stack with various degrees of granularity and scope.

We will look at the stack from Daniel Elizalde, which provides an effective perspective on the technology and the value proposition.

It starts with the device hardware, which is the tip of the iceberg, concrete and tangible.

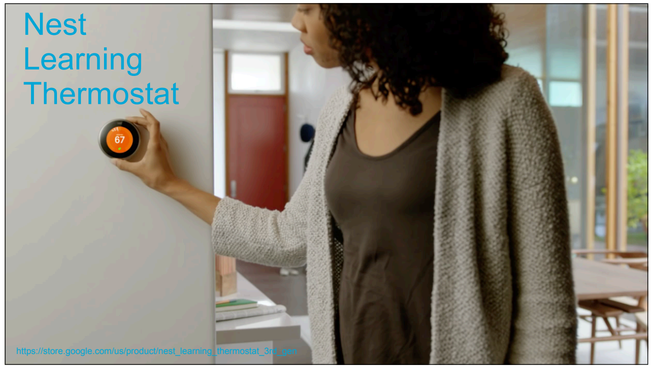
From the left, we will go all the way to the right, towards intangible, remote and abstract concepts.

Intangible, as we move to a digital world without physical manifestation of what is happening.

Remote, as many of the processes happen far from the physical product, distributed around the world

Abstract, as boundaries between elements becomes blury.

References:
- Daniel Elizalde’s IoT Technology Stack: https://danielelizalde.com



5

Let’s take the Nest Learning Thermostat as a concrete example of product-service system to navigate throughout this IoT technology stack.

While a traditional thermostat is passive, without knowledge about users and acting only when the user acts, the Nest Learning Thermostat watches user behaviour, learns from it to adapt its model, and operates autonomously.

The proposition is about taking care of home climate control on behalf of the users while best balancing comfort and energy consumption.

If you do not know about this product, we invite you to type in ‘Nest Learning Thermostat’ in your favourite search engine. Then, come back with us to start the IoT technology stack journey from the device hardware layer.

References:
- Google Nest Learning Thermostat: https://store.google.com/us/product/nest_learning_thermostat_3rd_gen

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6

The first layer of the IoT technology stack is the device hardware. Let’s see how it looks for the Nest Learning Thermostat.

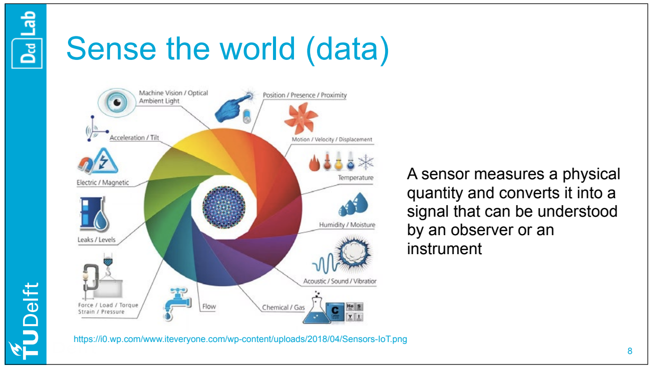
References:
- Alexander Hafemann on Unsplash: https://unsplash.com/@mlenny?utm_source=unsplash&utm_medium=referral&utm_content=creditCopyText

7

Out of the box, we note that the product must be versatile, offering compatibility with the many home settings. The ‘Heat link’ (white box on the left picture) can be connected to the boiler and establish a wireless connection to the thermostat, while the base (here with a blue sticker) can communicate to the boiler via wires. Both options are the actuator of the Nest, transforming its decision into a signal to the boiler.

It is common for designers to tear apart products to understand what is in them. Here at first glance, we can note a battery to supply energy, PCBs hosting small electronic and the screen.

References:
- Out-of-the-box: https://lifeofman.co.uk/install-nest-learning-thermostat-3rd-gen-y-plan-system/
- Tear down: https://medium.com/@justlv/nest-thermostat-e-teardown-and-on-making-beautiful-devices-for-the-home-ae6ada01bb26



8

Then, there are all the senses of the thermostat, allowing it to perceive the environment, capturing information about the real world.

Sensors play an important role here, measuring physical quantities and converting them into digital signals, which later can be transformed into data.

For the Nest Learning Thermostat, we can assume several temperature and humidity sensors. As this information is critical for the system, redundancy is one way to improve its accuracy.

Then, detecting user activity is the key additional feature. This is captured through motion, proximity and light.

The outer ring, enabling users to adjust the temperature manually, is also a critical sensor. It indicates when householders are not satisfied with the current temperature.

References:
- IoTOne: https://www.iotone.com/files/guide/internet-of-things--sensors---sensing_28.png

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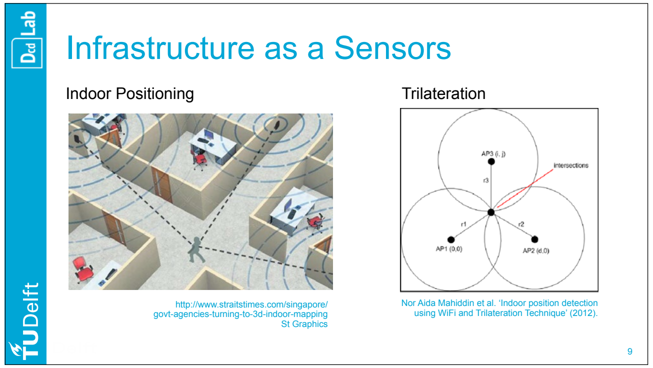
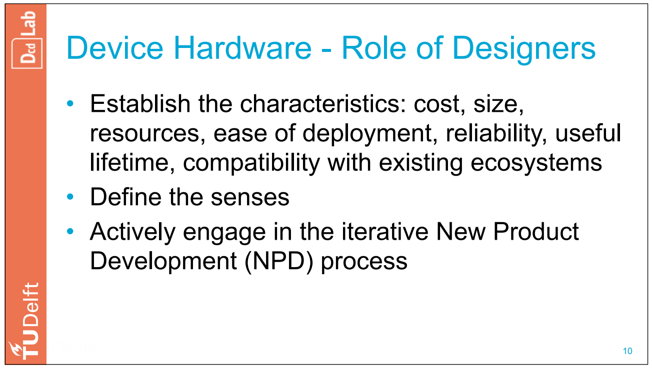


9

Infrastructure is itself often an important sensor. Wireless communication at all scale, from Bluetooth and WiFi to 4G and Satellites, enable to locate devices by trilateration. This process combines the location of antennas, which are static reference points, with the signal strength received from connected devices.

For the thermostat, knowing that your smartphone is connected to the home network is already a good indicator that you are at home.

References:
- St Graphics: http://www.straitstimes.com/singapore/govt-agencies-turning-to-3d-indoor-mapping
- Nor Aida Mahiddin et al. 'Indoor position detection using WiFi and Trilateration Technique' (2012). https://www.researchgate.net/publication/230771403_INDOOR_POSITION_DETECTION_USING_WIFI_AND_TRILATERATION_TECHNIQUE



10

Thus, the device hardware layer is about the physical things, from real world to digital world. At this layer, the role of designers is three-fold:

- First, they need to establish the characteristics of the physical thing. For example, their cost, size, resources, ease of deployment, reliability, useful lifetime, compatibility with existing ecosystems.

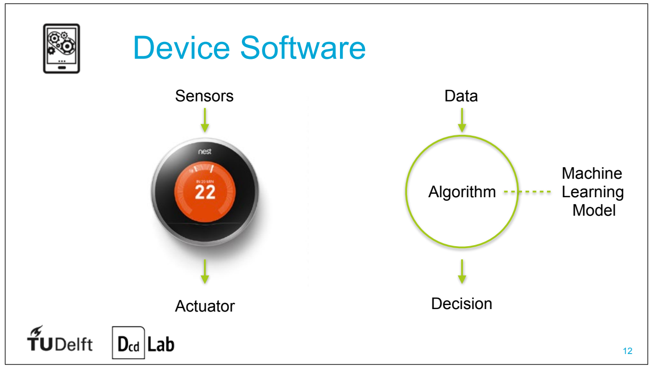
- Second, they need to define the senses of the thing, what information it should gather from the real world and which of the basic five human senses it should interact with. These two roles are on the shoulders of designers because they have a holistic understanding of the context.

- Finally, they need to orchestrate the iterative New Product Development process, or NPD. Here the challenge is the asynchronicity: this process does not follow the same pace as the iteration of the other layers. For instance, hardware iteration cycles are much longer than software iteration cycles.

11

Our series through the IoT technology stack led us to the second layer ‘device software’. This is the piece of software running locally, on the device.

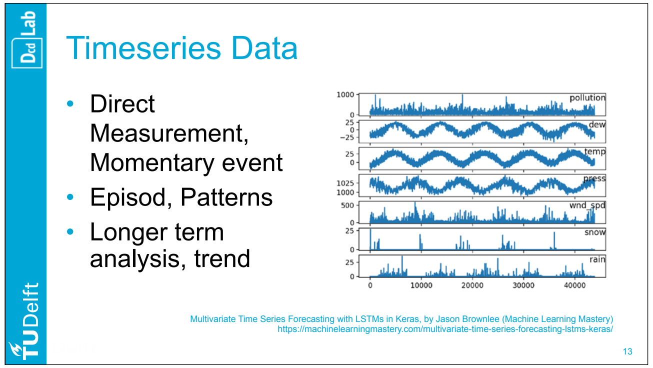
References:
- Alexander Hafemann on Unsplash: https://unsplash.com/@mlenny?utm_source=unsplash&utm_medium=referral&utm_content=creditCopyText



12

This is where the data acquisition takes place, providing inputs to algorithms.

In this case, this is a machine learning algorithm trained by data overtime to take a decision: a machine learning model.



13

IoT data has often the so-called 4Vs attributes of big data, standing for volume, velocity, variety and veracity. However, its main characteristic is its connection to time, so-called time series.

There are three time-lenses to look at IoT data.

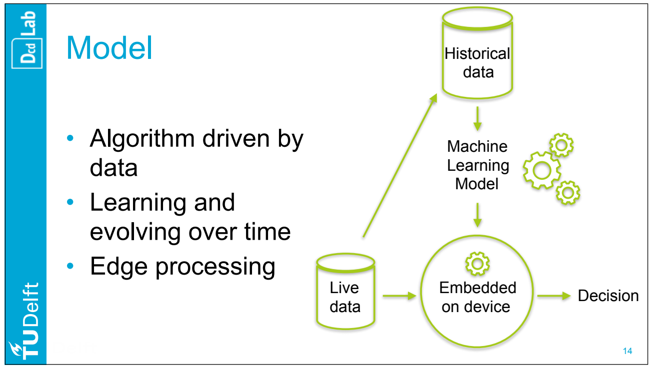
First, the direct measurement. It is a momentary event represented by a single data point: the value of a sensor at a given time. On this chart, these are every single variation.

Then, zooming out over a longer time frame, we can identify episodes and patterns. An example of these is the temperature, going smoothly up and down for each day.

Finally, the data can be stored locally or sent to another, more resourceful device for storage and long term analysis and trend.

References:

- Multivariate Time Series Forecasting with LSTMs in Keras, by Jason Brownlee (Machine Learning Mastery) https://machinelearningmastery.com/multivariate-time-series-forecasting-lstms-keras/



14

Machine learning models are often trained on the cloud, on a larger server, as the process requires a large amount of data and computing power.

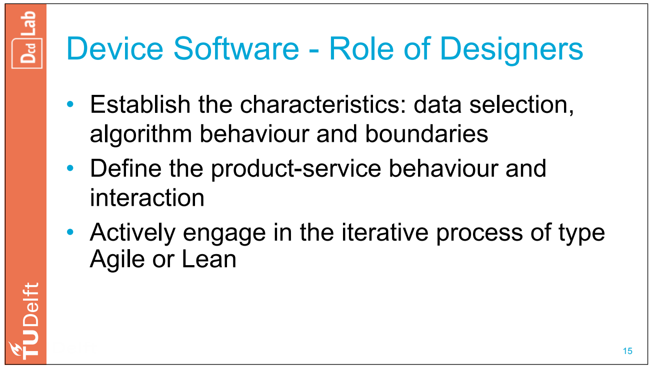
Then, it is compressed, embedded on the device, and can in some cases, continue to learn and evolve based on new data input.

This local algorithm is also referred to as edge processing.

It transforms data inputs into a decision, removing the need to send raw data streams to the cloud and wait for a decision to come back.

When the algorithm cannot run on the device because of resource limitation, the signal can be pre-processed to minimise the transmitted data.

These are ways to reduce data communication, to fasten the feedback loop and mitigate data leaks.



15

Thus, at this layer, what's in it for designers? Again, they should establish the characteristics of the device software.

What data should be selected, transformed to feed the algorithm or discarded?

What is the algorithm, driving the device behaviour? And more importantly, what are the boundaries of this behaviour.

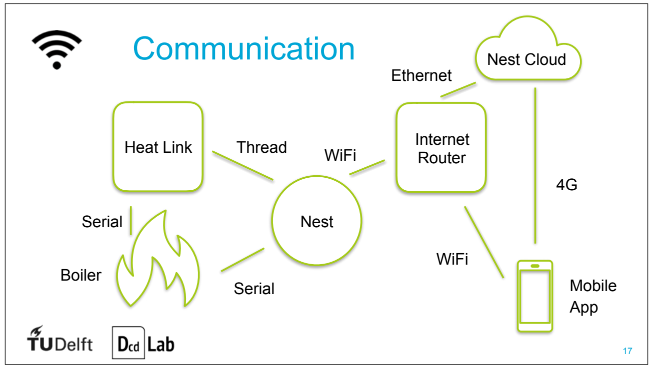
As we shift towards learning and evolving algorithms, it is crucial to anticipate unexpected algorithm behaviours and provide fallback solutions.

Finally, this is a very iterative process which requires designers to embrace agile and lean processes.

16

The third layer of the IoT technology stack is communication. It is about exchanging information with the rest of the world, making the step towards extending the Internet.

References:
- Alexander Hafemann on Unsplash: https://unsplash.com/@mlenny?utm_source=unsplash&utm_medium=referral&utm_content=creditCopyText



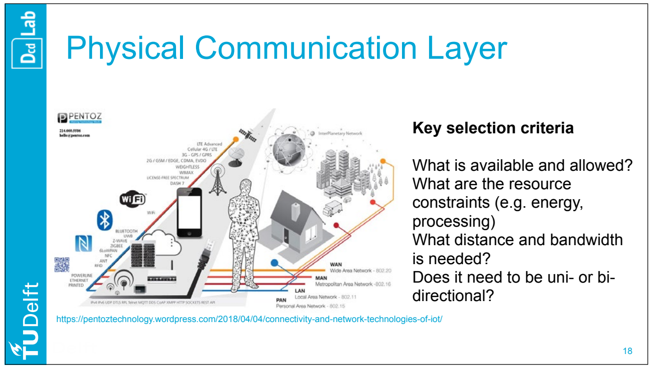
17

For the Nest Thermostat, the communication looks like that:

In the middle, the Nest connects to the households Internet router via WiFi, from which it can communicate with the Nest Cloud through the Internet.

The Nest mobile app can interact with the Nest via the Nest Cloud or directly through the WiFi network.

On the left, the Nest can directly control the Boiler via serial communication. When this wired communication is not possible, the heat link enables a connection via Thread, a wireless mesh network, to receive the Nest signals and transmit them to the boiler.



18

As we see, communication starts with physical technologies transporting the information. As this is a fast-changing landscape, there are many industry standards for all types of communication, emerging and being deprecated regularly.

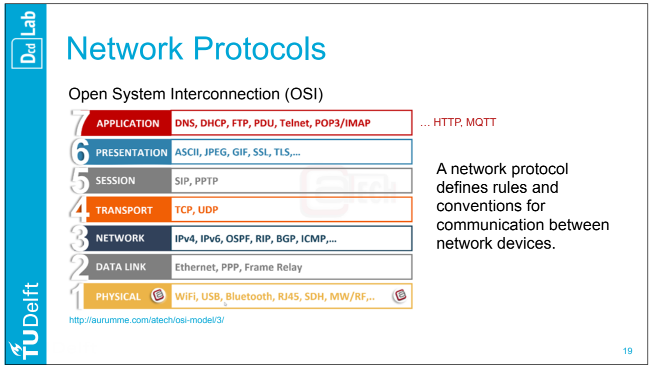
Navigating communication technologies thus requires a clear understanding of what is needed for the product-service system being designed.

Looking at the environment is always the first step. From a hospital to a household, from a single body to an urban-scale environment, options already available or allowed can vary significantly?

Then, what is the distance to cover and the amount of data to transmit? The bandwidth is the rate of data transfer measured in bits per second.

Some technologies offer the ability to transmit and receive data (bidirectional) while others work only one way.

References:
- Pentoz: https://pentoztechnology.wordpress.com/2018/04/04/connectivity-and-network-technologies-of-iot/



19

These network technologies are part of the first, physical layer of the OSI model, the Open System Interconnection standard reference framework to conceptualise data communication.

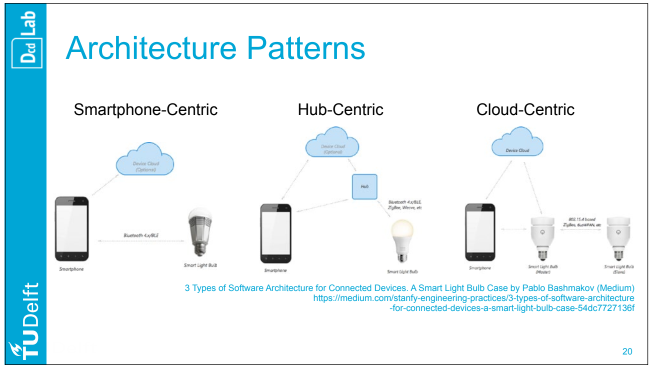
Communication relies on protocols, allowing devices to exchange information through a set of rules and conventions.

It is important to understand the basic jargon surrounding networking protocols as they infiltrate all parts of the IoT technology stack.

Beyond the physical layer, the Internet is especially characterised by the Ethernet, IP and TCP, respectively from layer 2, 3 and 4. Presenting information, layer 6 involves data translation, encryption and compression.

At the highest level, application protocols such as HTTP and MQTT define the purpose of the interaction between two devices.

References:
- Atech: http://aurumme.com/atech/osi-model/3/



20

The communication layer opens up the landscape from a single device to a network of things.

A system architecture is a conceptual model that defines the structure and behaviour of a system. It helps design and communicate about it. An architecture description is a formal description and representation of a system, organised in a way that supports reasoning about the structures and behaviours of the system.

In this context, we recognise three main architecture patterns for connected devices. Here, there are illustrated in the context of domestic connected light bulbs.

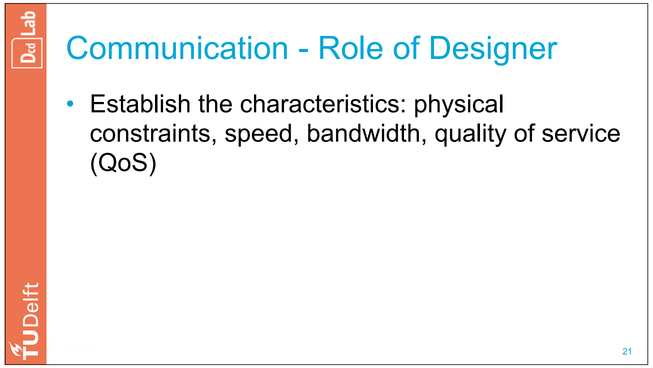
Smartphone-centric architectures establish a direct connection to a device. The device is only connected to the rest of the world via a smartphone. Setting up is easy and no additional equipment is required. The light bulb is no longer connected when the phone is away.

Hub-centric architectures involve a local hub, similar to a home Internet router. This hub often plays the role of a gateway, translating a local protocol such as ZigBee or Zwave into the Internet Protocol. In this setting, phones interact with devices via the hub. The hub is continuously available and offers higher computational capabilities than devices.

Finally, in a cloud-centric architecture, all devices connect to the Internet on their own, or one of them is automatically chosen as the master, playing the role of a gateway.

References:

- 3 Types of Software Architecture for Connected Devices. A Smart Light Bulb Case by Pablo Bashmakov (Medium) https://medium.com/stanfy-engineering-practices/3-types-of-software-architecture-for-connected-devices-a-smart-light-bulb-case-54dc7727136f



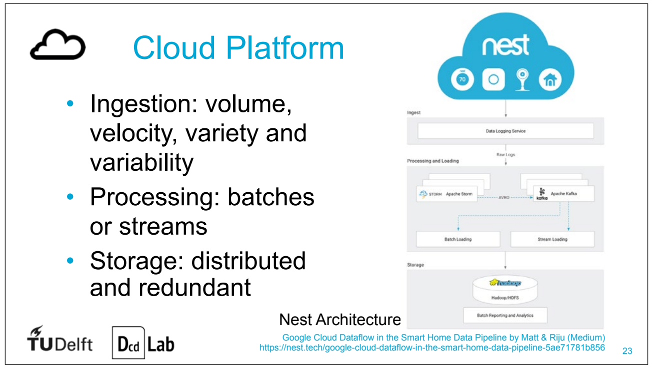
21

Once again, designers must establish the communication characteristics, including the physical constraints, the speed, the bandwidth, the security and the quality of service based on their holistic view of the product-service system.

22

In this fifth episode of our IoT technology stack exploration, we will look at the cloud platforms.

References:
- Alexander Hafemann on Unsplash: https://unsplash.com/@mlenny?utm_source=unsplash&utm_medium=referral&utm_content=creditCopyText



23

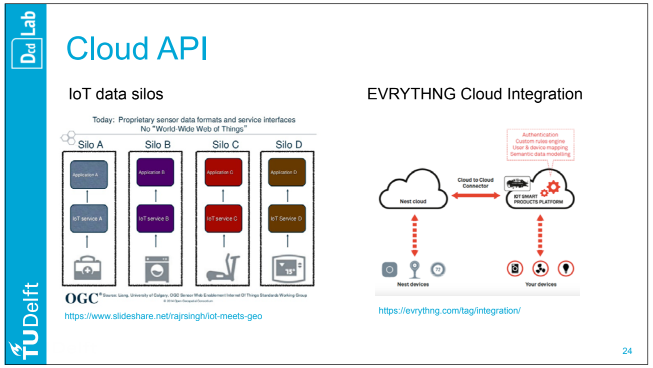
With the communication layer, data leaves the device and reach the cloud: a network of servers providing a set of data services including ingestion, processing and storage.

Ingestion refers to the ability to receive and handle the data from a very large and heterogeneous set of data. As we saw in the device software layer, IoT data is indeed characterised in the literature as the four Vs, standing for volume, velocity, variety and variability.

Processing is the analysis of this data to clean, extract and generate information. Stream processing handle data at ingestion time to provide an output result in the best delay while batch processing looks at a larger amount of data, often data already stored, to extract higher-level analytics.

Finally, storage is saving data in a distributed and redundant fashion to maximise scalability and robustness.

References:
- Google Cloud Dataflow in the Smart Home Data Pipeline by Matt & Riju (Medium) https://nest.tech/google-cloud-dataflow-in-the-smart-home-data-pipeline-5ae71781b856



24

As each cloud is a data silo, another key role of cloud platforms is the distribution of data.

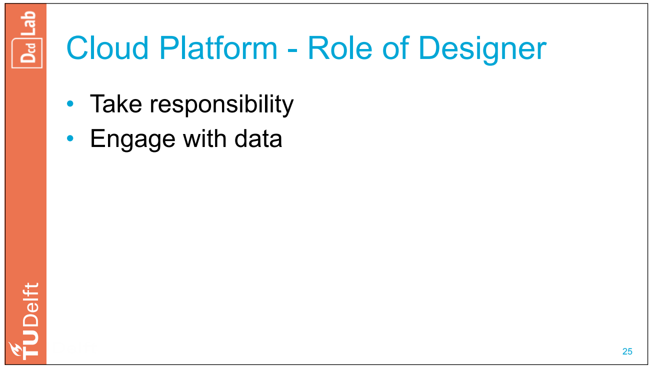
An Application Programming Interface, or API, is a computing interface to a software component or a system that defines how 3rd party software or systems should use it.

Through APIs, cloud platforms distribute data and interconnect with other clouds.

In this example, the API allows the interaction between the Nest cloud and Evrythng cloud, an IoT company focusing on industrial applications.

Cloud API allows 3rd party mobile and web applications to access data, thus building new product-service systems out of the same data.

References:
- IoT data Silos: https://www.slideshare.net/rajrsingh/iot-meets-geo
- EVRYTHNG Cloud integration: https://www.slideshare.net/rajrsingh/iot-meets-geo



25

This layer unleashes the power of data and requires designers to be aware of decision consequences.

With power comes responsibility, this layer is critical for the designer to ensure that technical decisions do not jeopardise the security and intimacy of the stakeholders.

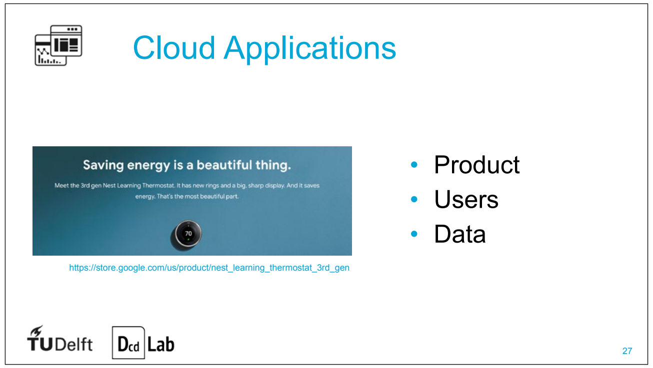
While intangible, the physical location of cloud platform infrastructure, as well as the terms of each cloud service drive the rules and future of the data they handle.

IoT data is a unique design material, cloud platforms enable designers to engage actively with data and their users to better understand what is happening and why; allowing to iteratively design relevant product-service systems.

26

We finally reach the cloud applications' layer, giving purpose to the whole IoT technology stack.

References:
- Alexander Hafemann on Unsplash: https://unsplash.com/@mlenny?utm_source=unsplash&utm_medium=referral&utm_content=creditCopyText



27 Cloud applications are combining device hardware and software, communication and cloud platforms to deliver product-service systems. For the Nest thermostat, the promise is an energy saving service.

With the IoT, the value-proposition is not centred on the device anymore. As we saw, beyond the device there is more opportunities for creating value. Thus, products increasingly turns into service model.

References:
- Nest Learning Thermostat: https://store.google.com/us/product/nest_learning_thermostat_3rd_gen

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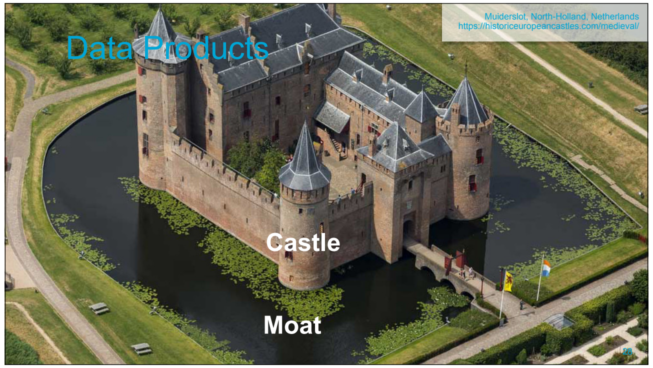


28 Like the previous layers, data is at the centre of the cloud applications. Looking back at our definition of the IoT, helping human gathering and building knowledge about the real world, the key component of cloud applications are the data product.

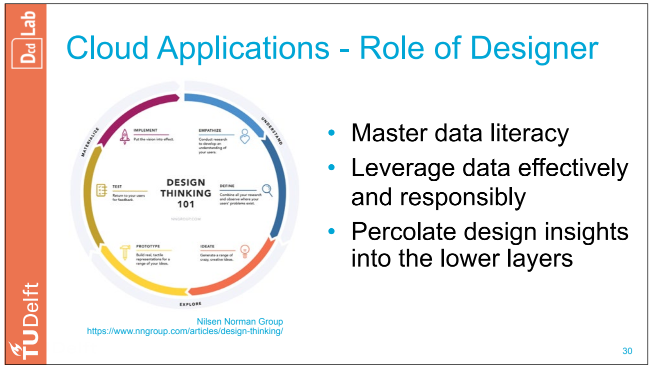
To explain what it is, let’s make a cultural pause and look at this castle.

From wikipedia, a ‘moat’ is a deep, broad ditch, either dry or filled with water, that is dug and surrounds a castle […] to provide it with a preliminary line of defence.

References:
- Muiderslot, North-Holland, Netherlands: https://historiceuropeancastles.com/medieval/
- Moat definition: https://en.wikipedia.org/wiki/Moat

29 This is how best to describe a data product. Data products are propositions which build up a ‘data moat’, a unique and impregnable fortification giving a definitive competitive advantage.

For instance the Nest thermostat is gathering many human activity insights enabling Google to grow and enrich its dataset, a unique material to train algorithms and extract insights.



30

Who are the users? What is the product? This should be the most familiar layer for designers. However, it comes as an umbrella, at the top of the technology stack, in very abstract terms.

Here, the key role for designers is to make effective and responsible use of data to understand, explore and materialise these product-service systems.

It requires mastering data literacy throughout the IoT technology stack to iteratively percolate design insights into the lower engineering layers.

With this ability, designers can ensure that their design is materialised and the appropriate data collection is in place to enable evaluation, reflection and insights for the next iteration.

References:

- Design Thing, Nilsen Norman Group: https://www.nngroup.com/articles/design-thinking/

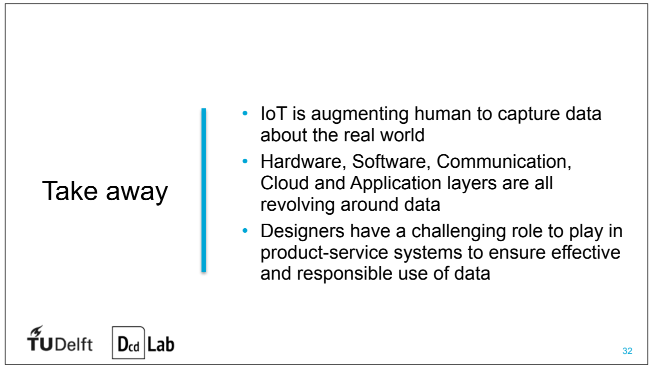
31

This is the conclusion of our series on the Internet of Things' Technology Stack.

We covered a lot of ground, with many jargon hopefully offering knowledge pointers to explore some of these concepts further.

References:

- Alexander Hafemann on Unsplash: https://unsplash.com/@mlenny?utm_source=unsplash&utm_medium=referral&utm_content=creditCopyText



32

To wrap up, we explored what the Internet of Things is, a network of things augmenting human to capture data from the real world.

The device hardware involves the physical device, interface between real and digital worlds.

The device software acquires data, take decision on the device and transmit data to more resourceful devices.

The could platforms ingest, process and store this data, creating the value of the product-service system.

The cloud applications gives the purpose of the product-service system, defining the product, user and data in a holistic view that percolates through all technology layers.

Using the IoT technology stack, we identified the technological elements of a product-service system. While this layered perspective help reducing the complexity, design iterations should be holistic, tuning all these layers in parallel to find the appropriate balance for the targeted goal.

Finally, we highlighted the key decision that designers should make while designing with IoT technologies.