LECTURE 8: AZURE IOT HUB AND THE SENSOR LIFECYCLE

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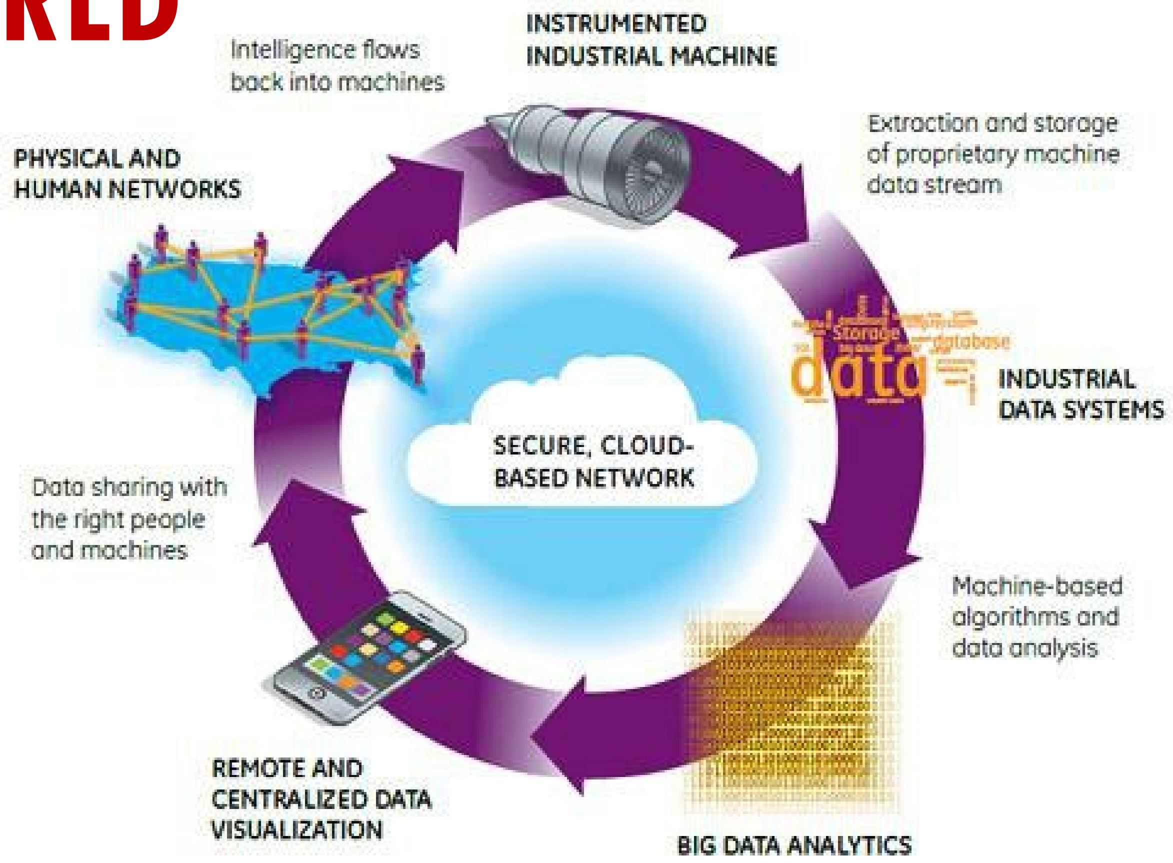
THE FUTURE SMART WORLD

Puzzles…

- Who “builds” this world?
- Will they maintain it properly?
- Can the devices be trusted?



http://www.plmconnections.com

LONG-STANDING ISSUE WITH SENSORS

People have talked about using sensors to create a “smart world” since 1980’s, but it hasn’t been as simple as they imagined!

It is fairly easy to put RFID tags on devices, but those are passive.

In fact “full fledged” IoT with sophisticated sensors and actuators poses a wide range of challenges that we are only starting to appreciate.

IOT IS EVERYWHERE, BUT POORLY MANAGED

Your Internet router, and networked printer

Cortana/Alexa/Siri/Google Nest

Your TV and home entertainment system

The network-connected microwave, fridge, range.

Smart hot-water heater, and A/C, and room heating units

Smart power meter, to connect them all together

Smart water meter (might even be able to diagnose leaks)

Solar panels on the roof, energy storage batteries in the wall

IoT DOESN'T NEED TO BE OBVIOUS!

Estel: Italian design firm specializing in smart offices

The technology is subtle but pervasive. Dozens of smart devices

… EXAMPLES OF IoT IN THE OFFICE

Room occupancy, temperature, humidity sensors and sector control

Sensor to detect exterior light, actuator to control lights & window shades

Desktop microphone for conferencing

Smart copier/scanner with network-enabled functionality

The elevator system

The expresso machine that automatically orders new coffee packs

Door locks that check ID cards

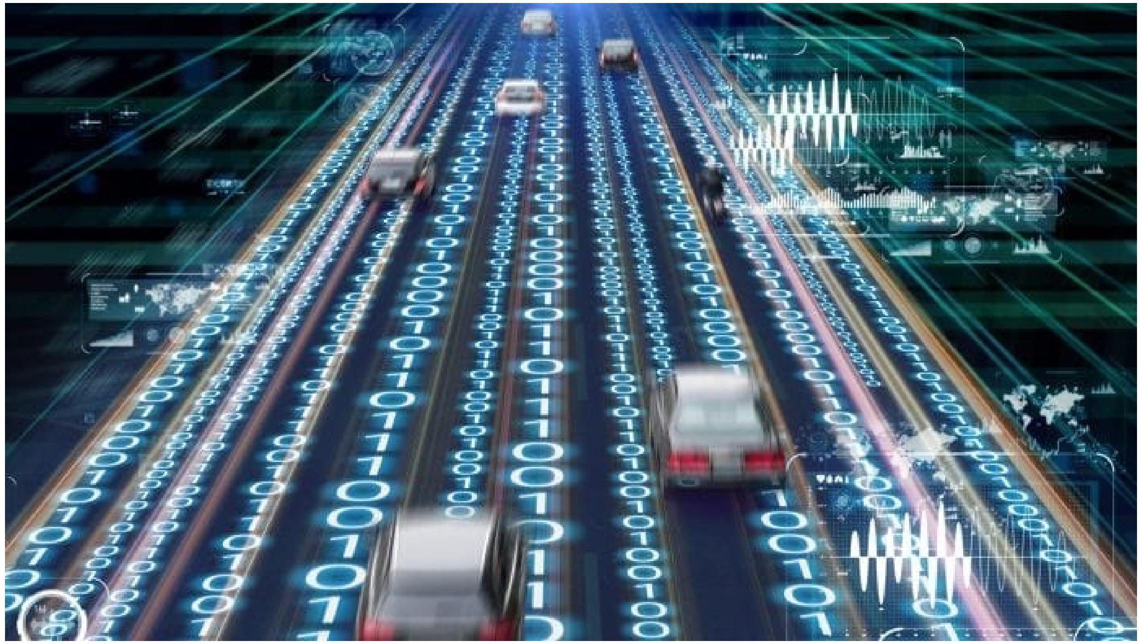
… EVEN THE ELECTRIC POWER GRID IS SMART

Most of the world's bulk electric power systems are becoming smart

This is IoT on a "grand scale" and covers more than just power: coal/gas delivery, scheduling of power plants, maybe even water delivery, too.

But this means that the power grid will need to keep a close eye on everything using electric power, or generating it. More IoT!

… THE LIST REALLY IS ENDLESS



Smart farm

Smart city

Smart highway

Smart emergency first-response….

FIRST QUESTION: <u>CONTEXTUALIZATION</u>

How do IoT devices know which room they are in?

- Alexa, adjust the shades to block the glare on my display
- Siri, use active noise cancellation to block that street noise
- Cortana, find me a nearby conference room we can book for an hour.

… in addition to the IoT devices themselves we will need increasingly detailed "environmental maps" for everything, down to individual rooms!

… CONTEXTUALIZATION IS A CLOUD COMPUTING TASK WE MIGHT DO IN A μ-SERVICE!

Needs a database of knowledge about the residents of a home

We also have IoT sensors and knowledge of where they are located.

Occupant says "Hey Cortana, can you block this glare?"

You do a query to figure out that the sunlight from a particular window in the TV area is reflecting onto the occupant, who is on the couch there…

PRIVACY?

One worry would center on privacy

If the layout of your apartment is on the cloud, and it tracks where you are and is listening to you for voice commands, this seems very intrusive!

"Hey Siri" works by having one hardware chip listen for "Hey Siri" but nothing else. Then when it hears that, the second chip is enabled to listen to your voice command, but then disabled again. Is this good enough?

WHO KEEPS THIS STUFF SECURE + ROBUST?

Even if every light bulb "could" have a computer in it, why would this benefit anyone, and who would make sure the broken ones are replaced?

How can we protect privacy and ensure that these things are secure? What costs could be incurred for violations?

What if a sensor malfunctions? Can we figure out that it needs repair?

SITUATION TODAY?

Very poorly managed, huge numbers of IoT devices yet very little attention to software upgrades, network security issues raised.

There are network-enabled printers that turned out to have entire spy computing systems embedded in them, to retain copies of everything.

Largest "zombie/bot" population? By one estimate, it may be Internet WiFi routers with default password settings!

AZURE IoT TODAY: AIMING FOR A MINIMAL BUT ADEQUATE LAUNCH POINT.

Microsoft has focused on IoT for corporate customers with huge numbers of smart devices, and little control over them.

And within that first step, they focus on management of the "fleet" of sensor and actuator devices:

- Unmanaged sensors are a danger and a nightmare to the "owner"
- Seems like a necessary first step, in any case
- Can we "secure" the IoT devices, and make them "trustworthy"?

KEY ARCHITECTURAL ELEMENTS?

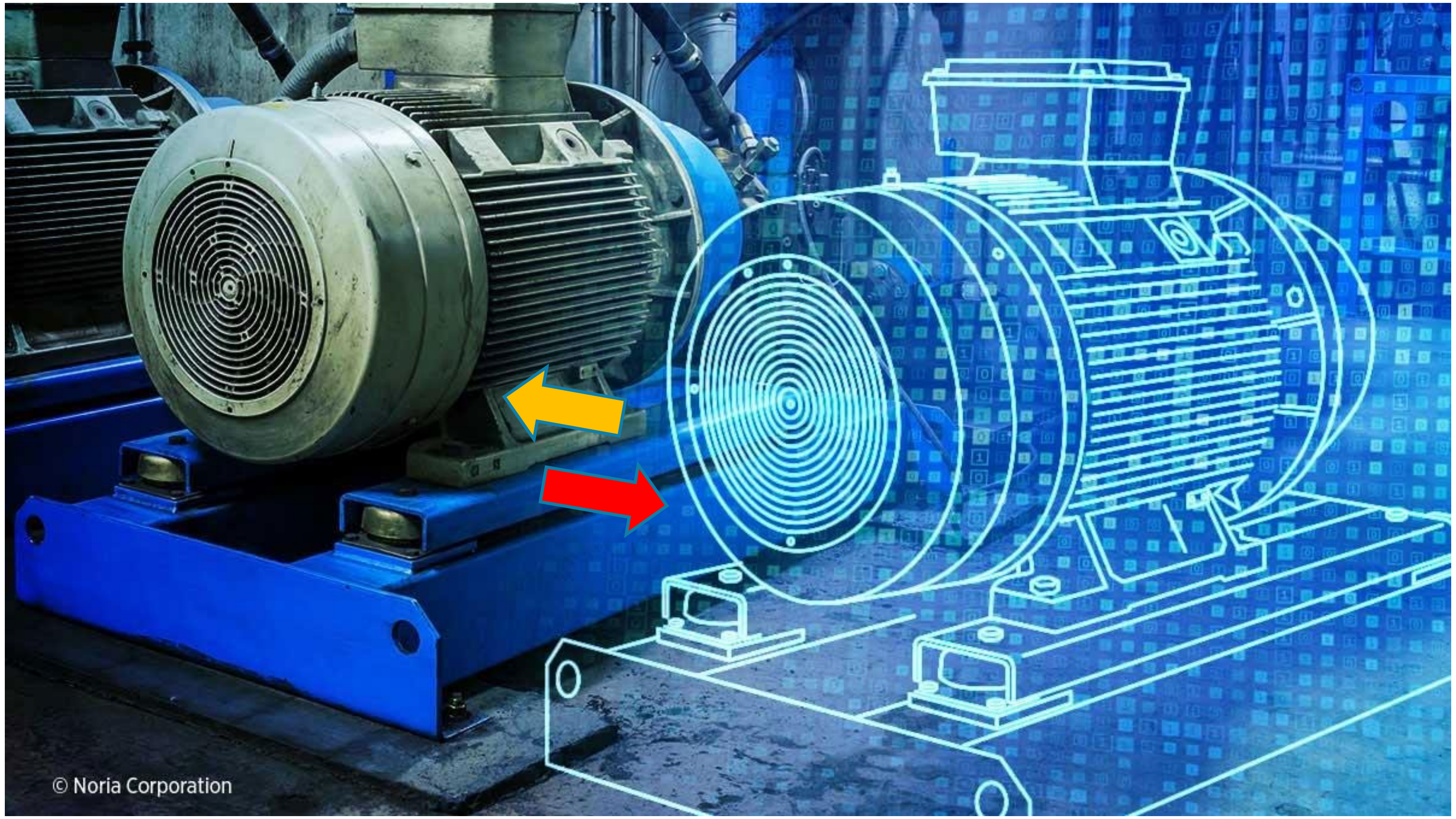
Microsoft product: Azure IoT Hub, Iot Edge and Intelligent Edge

- First, the hub handles secure registration of devices and status tracking
- Next, it automates software upgrades
- It deals with issues of intermittent connectivity
- For devices that can be controlled from the cloud, it creates a “model” to enable you to perform those control actions

REMINDER: DIGITAL TWIN CONCEPT

We have some physical devices, like these coffee roasters.

They are equipped with sensors that monitor conditions and actuators, used to control the device remotely.



In the cloud, we maintain a digital representation for the turbine, like this engineering diagram. The software sensors and actuators in the cloud representation are virtual control points wired to the real-world sensors and actuators.

AZURE IOT HUB IMPLEMENTS THIS CONCEPT

The hub is a database and we can understand it as holding the engineering diagram and also the “virtual” sensors and actuators.

Azure uses a real database for this purpose (SQL server).

A form of device driver links each virtual sensor to its real-world counterpart and each actuator to its real-world control point

AZURE IOT HUB: DATABASE OF SENSORS.

The first step centers on secure registration of devices. The Azure IoT Hub manages a scalable database of sensors and associated data.

The enterprise owner also records information such as:

- Device make and model,
- Software revision level, battery lifetime, when it was last serviced
- Where it is located, role it plays (information for contextualization)
- Additional application-specific information or “knowledge”

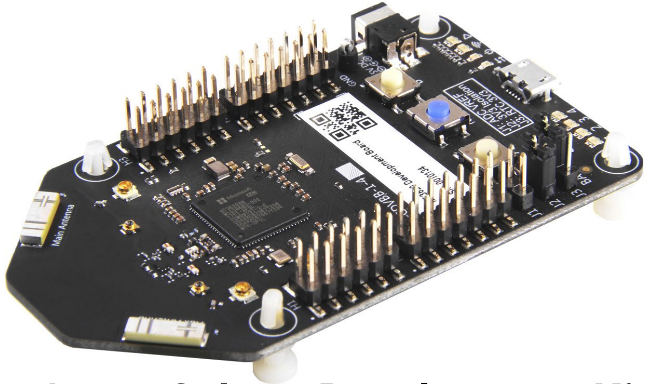
THIS MAKES IT AN <u>ACTIVE</u> DATABASE!

In a normal database the data tuples are just plain old data objects.

In Azure IoT Hub, the objects in the database are intended to hold meta-data on behalf of the "real" sensors and actuators, and to keep this data in sync with the actual sensor or actuator *when connectivity is possible*.

In effect, we now have meta-data describing the sensor combined with live properties (like battery level, photos cached, filter settings) that are wired to the actual device and change in real-time!

DEVICE SECURITY



Azure Sphere Development Kit

The level of security for today's network-enabled IoT devices is poor to non-existent, making them way too easy to hack or disable.

So Microsoft has a new product aimed at sensor *manufacturers*. The Azure Sphere is a special low-power security chip that embodies a hardware root of trust and low-power cryptographically protected HTTPS.

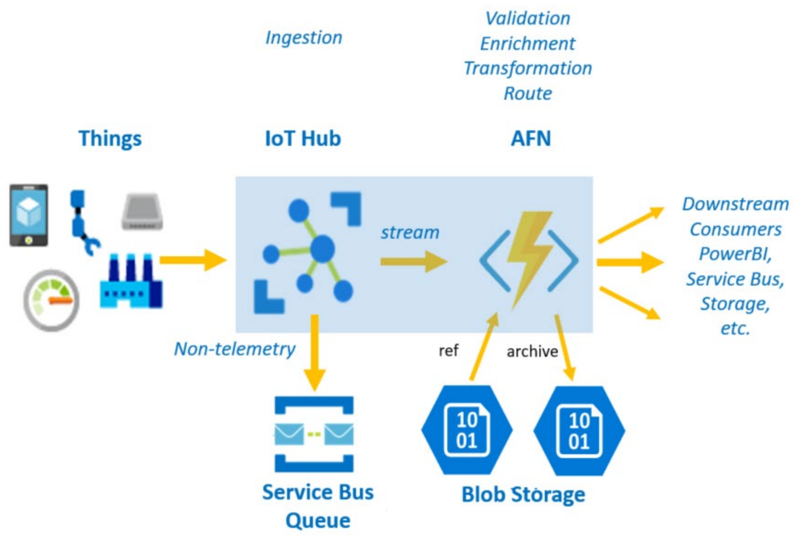
With Azure Sphere, device manufactures can secure existing sensor products, and the resulting sensors will interoperate with Azure IoT hub.

IOT PROGRAMMING VIA TEMPLATES

Like much of the cloud, Azure IoT offers “recipes” that developers download and then customize.

Here is an example from a scenario that they “story-board” on the Azure IoT Hub website.

This one relates to smart manufacturing



HOW DO "RECIPES" LIKE THIS WORK?

In fact they are tied to large amounts of

- Video training materials
- Actual demo code you can download and try, then customize
- Written documentation

For this example, visit https://github.com/microsoft/IoT-For-Beginners. It has a *lot* of content (scroll past the index at the top, which is in a GitHub style that might confuse you. The welcome and overview is *below* the list of contents)

EVERY AZURE IOT DEVICE HAS A "PROXY"

Many devices have limited network connectivity and won't always be online.

So in Azure IoT Hub, every device has a cloud-hosted "representative": a software agent that can respond to device operations 24x7, and then will push updates (like new software revisions) when an opportunity arises.

The agent can also schedule maintenance operations.

PROXY PROGRAMMING

In this Azure proxy mode, you can send information to a device even if the device is currently disconnected! The proxy is always available.

For example, a firmware update or patch, or new device configuration.

But obviously the action can't occur until the device connects. So there is always a back-and-forth: Event "to" the device, and later, an event "back". Applications will need to work in this very asynchronous way.

QUALITY OF SERVICE ISSUES

For many devices, network quality is also an issue.

Over time, a network link might be unavailable, or available but slow, or temporarily very fast (at a high price).

In normal networks we don't think about this much. But for IoT, our applications may need to be dynamically responsive as conditions change.

THE QUALITY OF THE SENSOR ITSELF IS ALSO A SERIOUS CONCERN

With large numbers of sensors we often get redundancy

Wood and Marzullo explored this in a system called Meta here at Cornell.

Key idea: first, that sensors have “range of accuracy”, and second that time also has a range of accuracy. Finally, that by leveraging this insight, we can actually identify and correct for many kinds of inaccuracy!

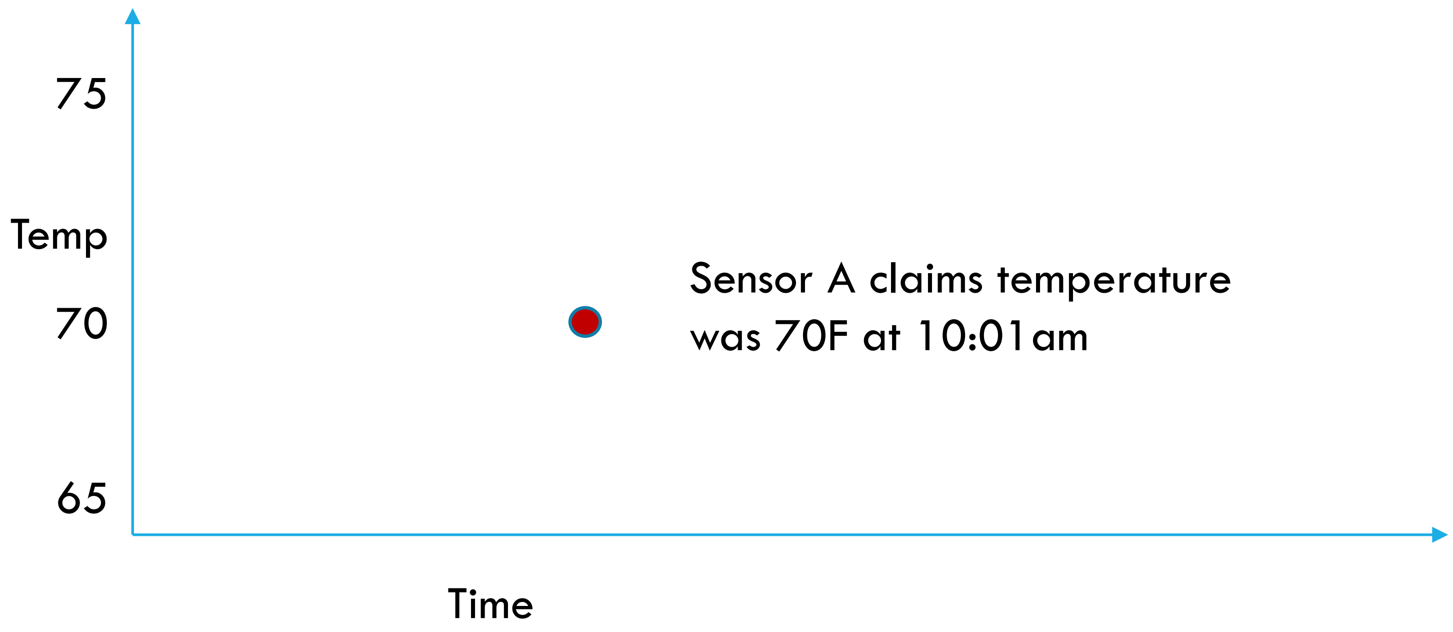
CLOCKS ALSO HAVE LIMITED ACCURACY

There are standard protocols for synchronizing them.

But at any instant in time, clocks could still have drifted from the exact time.

The term clock *skew* is an estimate of the worst-case drift between two non-faulty clocks, if you were to read them at the same instant in time.

DEEP DIVE: HOW DOES SENSOR ACCURACY IMPACT THE WAY WE MIGHT USE THEM?



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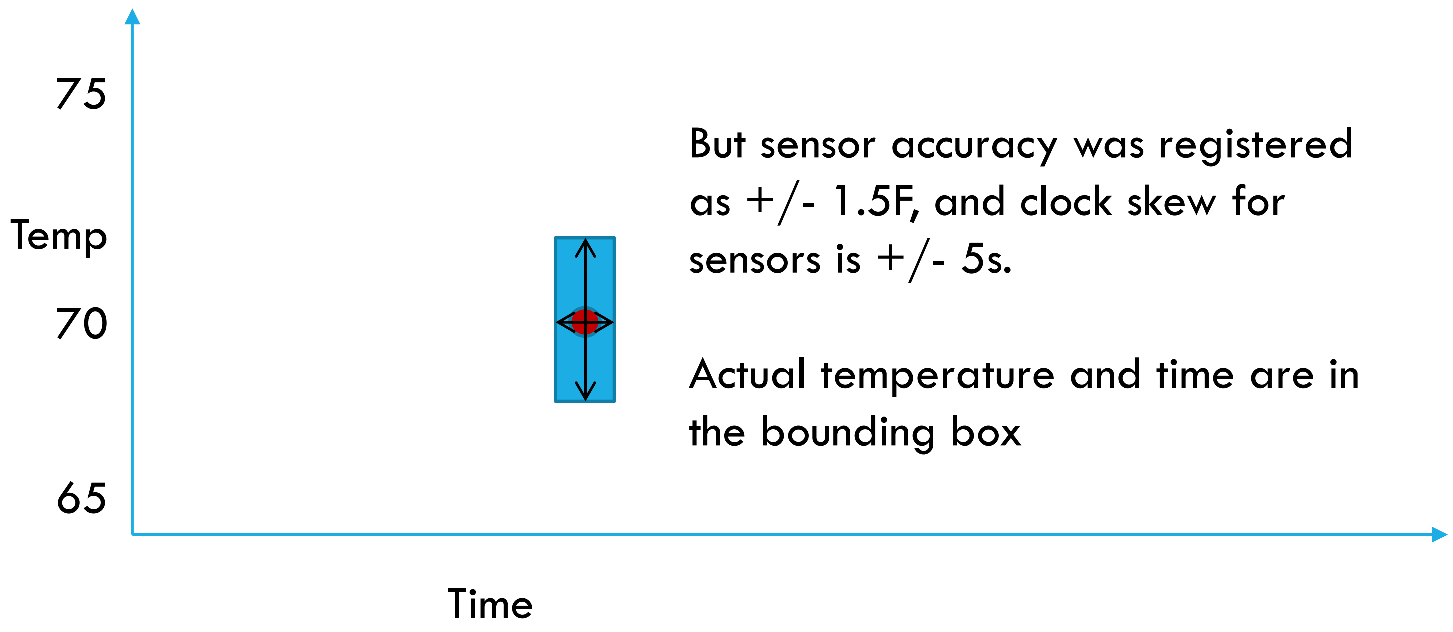

But sensor accuracy was registered as +/- 1.5F, and clock skew for sensors is +/- 5s.

Actual temperature and time are in the bounding box

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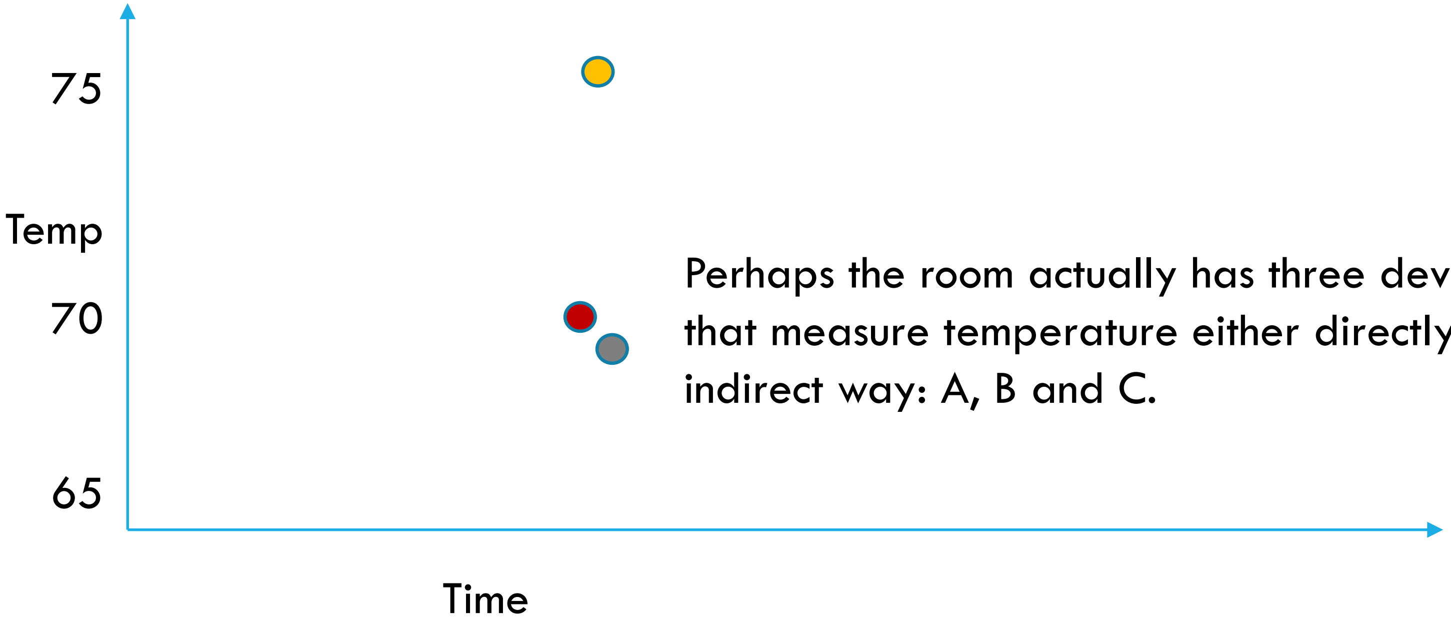

Perhaps the room actually has three devices that measure temperature either directly, or in some indirect way: A, B and C.

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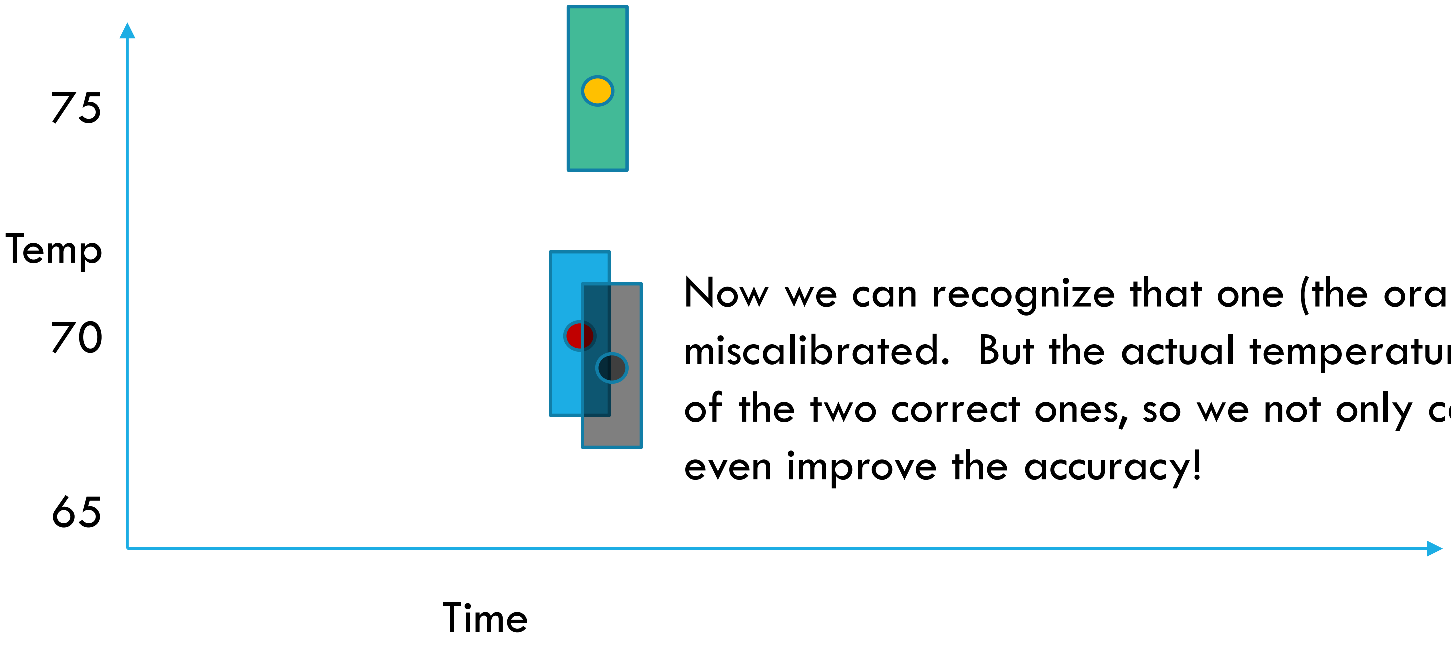
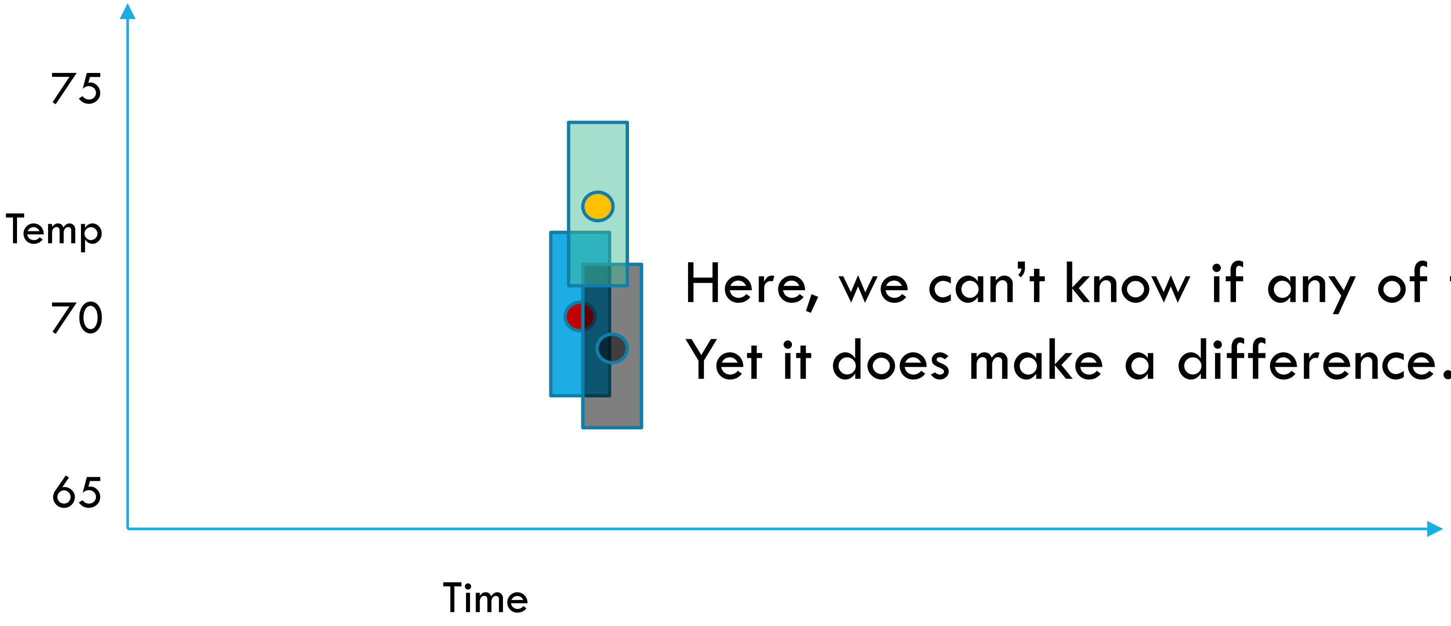


Now we can recognize that one (the orange one) is faulty or miscalibrated. But the actual temperature must be in the overlap of the two correct ones, so we not only can figure this out, we can even improve the accuracy!

WHAT CAN WE DO IN THIS CASE?



Here, we can't know if any of them is faulty!
Yet it does make a difference…

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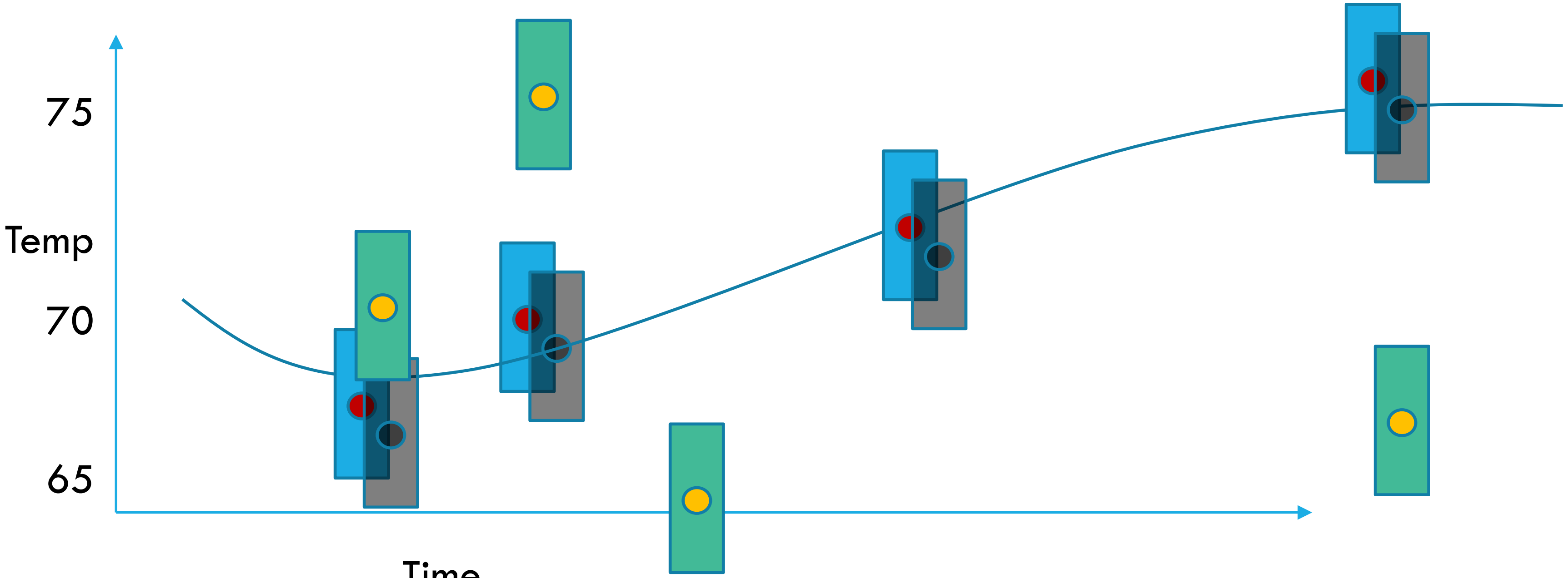

Knowledge of temperature *trends* could give us a further way to improve the data! Also, by now we can see that we need to schedule service on the yellow sensor, or remove it entirely.

META: "RULES" FOR COMPUTING WITH IMPRECISE SENSORS

Suppose we tell the smart system to "turn on the office A/C if the temperature rises above 71F"

Does this mean "if the temperature *might* be more than 71?" Or "if the temperature *is definitely* more than 71?"

The correct action is very different! In our example, the temperature is probably 70.1, but *could* be as high as 71.6

"MIGHT" VERSUS "DEFINITELY"

Might is a way to talk about "any value in the bounding box."

- If the temperature is 70.1 +/- 1.5 at time 10:03 +/- 5s, it "might" have any value in the temperature range, or the time range.

Definitely would mean that the allowed range has "no intersection" with the bounding box

- In our example, the temperature is definitely more than 69F

TEMPORAL ACCURACY CONCERNS

Focusing on clocks, Fred Schneider likes to distinguish three properties:

- Precision: How close is a clock to other non-faulty clocks?
- Accuracy: How close is the clock to “true” time?
- Drift: How quickly is a clock losing precision or accuracy?

Recall: For a pair of clocks, the “skew” is their difference if measured at the same instant in true time. Drift is the “rate at which skew increases.” Precision and accuracy are *both* forms of skew.

EXAMPLE

Suppose that an automated vehicle has a guidance system (perhaps assisted by the cloud) that believes it is safe to drive at 30mph at some location until 10:04:31.825 today, but then must pause until 10:05:31.825

Now, imagine that the vehicle and the guidance system don't have perfectly synchronized clocks.

Would we want "accuracy" or "precision" here? How about "might" versus "definitely": should car stop if it "might" be at that spot at that time?

THIS ACTUALLY HAS HAPPENED!

The Patriot anti-missile system was implemented as a two-processor system.

A radar unit, on the ground, computed the trajectory of an incoming threat and tells the anti-missile when and where to intercept the target. Then the anti-missile launches and makes a pinpoint rendezvous.

During the Gulf War, Patriot system often ran for many days without a reboot. Clocks drifted, and the anti-missile defense was often "late for the rendezvous" – causing it to miss the incoming Iraqi Scuds

MANY IOT APPLICATIONS NEED AWARENESS OF TEMPORAL AND MEASUREMENT LIMITATIONS!

Today's cloud systems are designed with CAP in mind.

They are pretty relaxed about using stale data if fresh data isn't handy

But this can easily cause the kinds of problems we're talking about! And now we can see that even with fresh IoT data, applications must be designed carefully to be smart about how they use that data!

MORE PUZZLES: “INFORMATION FLOW”

Because the IoT world will be large and geographically distributed, information needs to be moved around to carry out intelligent tasks. Yet customers may insist that we limit and control the flow of private data.

PRIVACY

Suppose that the cloud learns sensitive information

- If Siri/Alexa/Cortana can hear your commands, it can listen to you.
- Who owns that information it gathered?
- Who should be permitted to listen to it?

It would be nice to say "all my private stuff stays in my house" but only the cloud really has the resources to understand everyone at large scale

Extra: not important, will cover if time permits

SECURITY

Beyond personal privacy, companies developing new products are at risk of competitors spying on them!

They benefit from the technology, but if their IP gets stolen, they lose it all!

So there are questions of protection not of private data, but also of company IP. But if you own your private data, how will the system figure out which remarks are private and which are related to your job?

Extra: not important, will cover if time permits

FAULT-TOLERANCE

With so many moving parts, some will fail!

In fact failures can occur at every level

- A sensor could go offline
- It could stay online but send confused/incorrect data, or bad timestamps
- The network connection could freeze up or break
- The cloud servers could shut down or be reconfigured

Extra: not important, will cover if time permits

EXAMPLE: LANDLORD'S MANAGEMENT TOOL

To see how these can come into conflict, consider a solution aimed at the landlord of a large residential complex.

It might have hundreds of units (apartments or condos)

Landlord needs to operate this intelligently

Extra: not important, will cover if time permits

AVOIDING HARM TO A BUILDING

In fact a major goal for smart buildings is to anticipate problems and fix them, perhaps even before they become serious.

Think about an apartment complex with a forgetful tenant in a drought area. If he starts the shower running but forgets and goes shopping, huge water waste can occur. Someone should shut the water off!

But then there is a privacy issue raised: will this reveal that the tenant has early senile dementia? He could be harmed if this became known.

Extra: not important, will cover if time permits

SIMILAR ISSUES

Window left open and yet heat is on. Stove was left on, or lights, or TV… but tenants aren't home. Microwave set to 30 minutes instead of 30 secs.

Tenant falls and can't get to a phone or call for help.

Fire in the area. First-responders need to know where people are located.

Extra: not important, will cover if time permits

IOT CAN HELP!

The challenge is to build trustworthy solutions that won't violate privacy and yet will help in cases like these.

The answer is to create systems that safeguard your data by keeping it close to where they gather it (which is why Azure IoT Edge is designed to even live right in the home).

When data does get sent to the cloud, it should be for a specific task. Then, when finished with that task, "leave no trace behind".

SOCIETAL BALANCING ACT!

Those of us who will build these systems need to decide what to do! And worse, we can't even trust the sensors themselves!

The law is far behind the technology curve. Don't expect to find answers in courtrooms for a long time.

Yet because companies ultimately have a revenue and profit motive, if you focus purely on corporate goals, you might do something evil.

SUMMARY

Tackling the IoT opportunity will be a huge opportunity, but also a huge investment and an enormous amount of work.

Today's cloud is incredibly powerful and this existing powerful solution will make a big difference.

But getting from here to there will still require new technology development.