

# Service-oriented Middleware for the Internet of Things: A Perspective

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# What is a Thing?

- A **Thing is a physical object** that interacts with the physical world and with the Internet
  - Two sides: a **physical “thing”** and a **service**
  
- On the software side, a **Thing is a service** that
  - Acts upon or senses the physical world
  - Contains physical attributes (position, orientation, ...)

# From the Internet of Things to the Internet of Services



## Internet of Things

*Global network infrastructure, linking physical and virtual objects through the exploitation of data capture and communication capabilities*



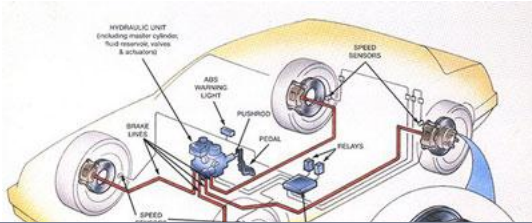
## Internet of Services

*An umbrella term to describe several interacting phenomena that will shape the future of how services are provided and operated on the Internet*

But...

# How to Sustain SOC in the IoT

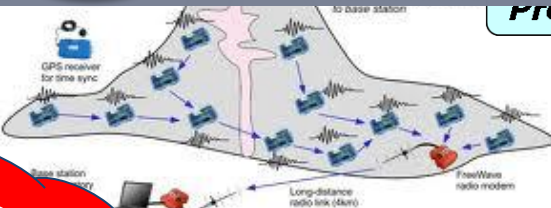
Numerous



Toward a Service-oriented Middleware for the Internet of Things

Embedded

Diverse



Provider

Broker

Consumer



Constrained

Volatile

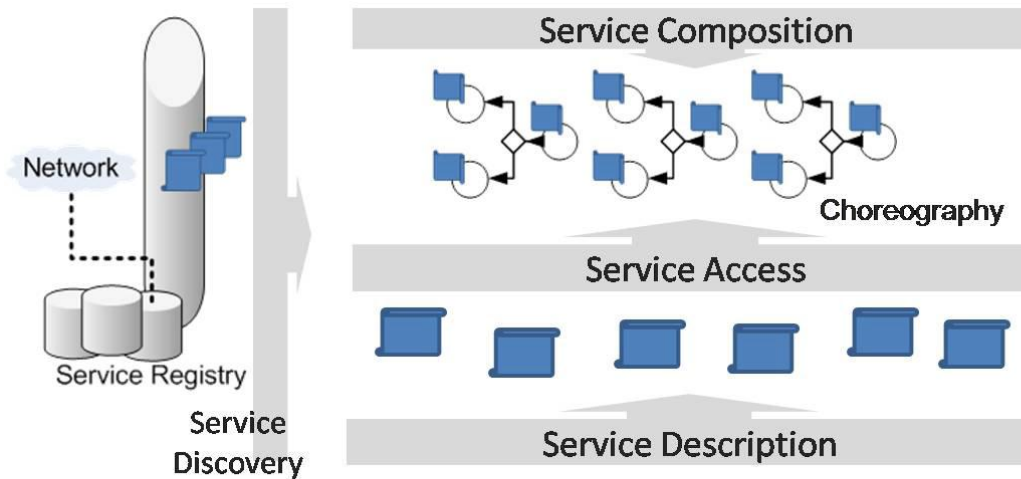
Shared

Unknown

# SoM for Things: Outline

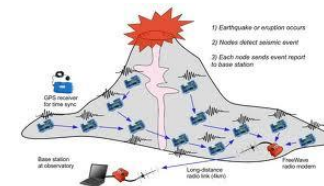
- Challenges for service-oriented middleware
- Background
- Toward facing the IoT challenges
- Conclusion

# A Glance at Service-Oriented Middleware

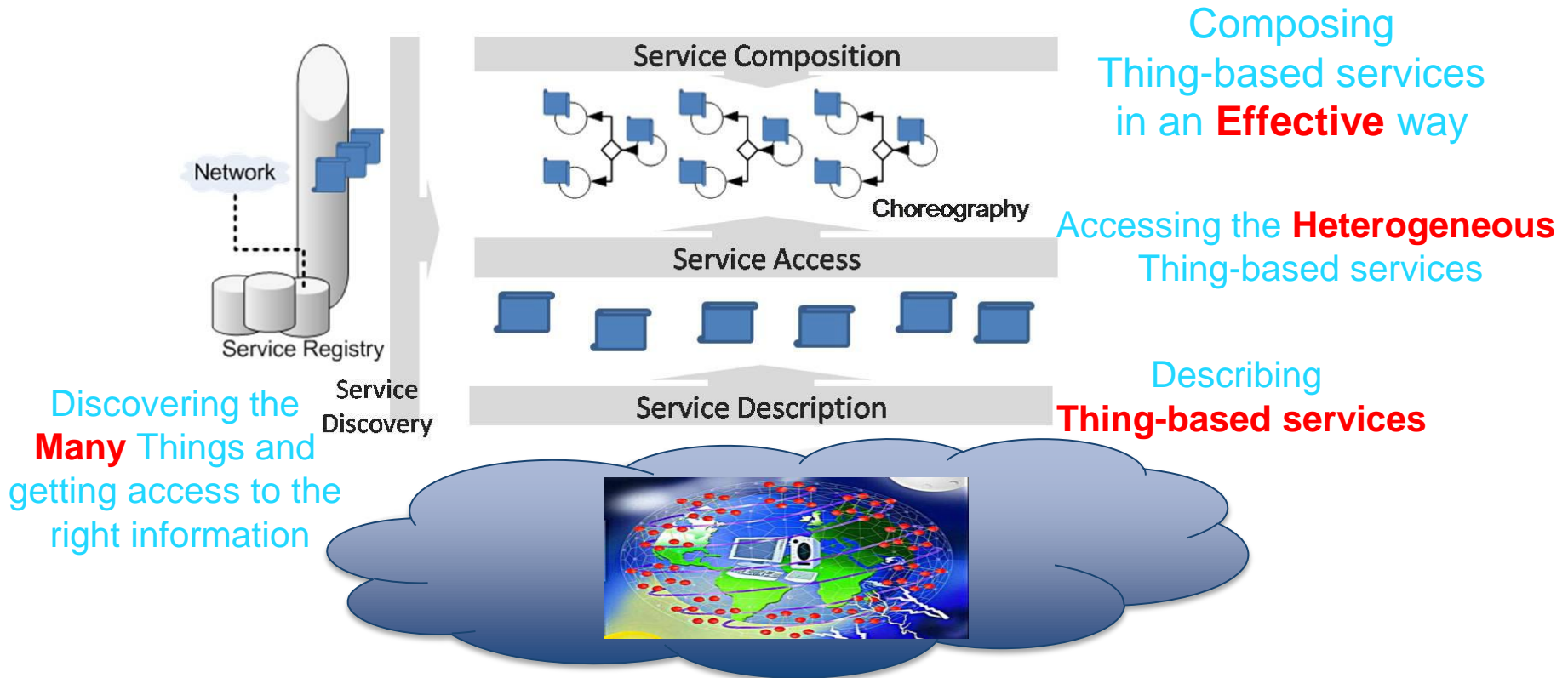


# Focus on the IoT Challenges

- **Scale**
  - Number of Things starting in the millions
- **Heterogeneity**
  - Wide diversity of things
  - Heterogeneity of same-type devices
- **Unknown topology and data availability**
  - Highly dynamic networking
  - Not every-where any-type
- **Multi-agent conflicts**
  - Concurrent access to shared actuators



# Service-Oriented Middleware for the IoT



# State of the Art: SOC as a core enabling paradigm

- Overall agreement on required SOC evolution
  - *E.g., Hydra, makeSense, SATware, Sensei, Socrates, TinyWS...*
  - Composite services to combine available knowledge
  - **Dynamic** service discovery to face unknown environment
  - Discrete and **Continuous** service access
  - **Lightweight** services
- Still... divergence in the enactment of the paradigm
  - WSN as a Service vs Thing as a Service
  - Thing-centric vs Content-centric

# State of the Art: But IoT Challenges Largely Unsolved

- Facing Scale
  - Applies traditional distributed computing paradigm, e.g., P2P
  - But revisiting network topology is not enough as we are dealing with coordinating thousands of things
  
- Facing Heterogeneity
  - Builds upon semantic technologies and metadata
  - Virtual/semantic sensor
  - But metadata often inaccurate or incomplete

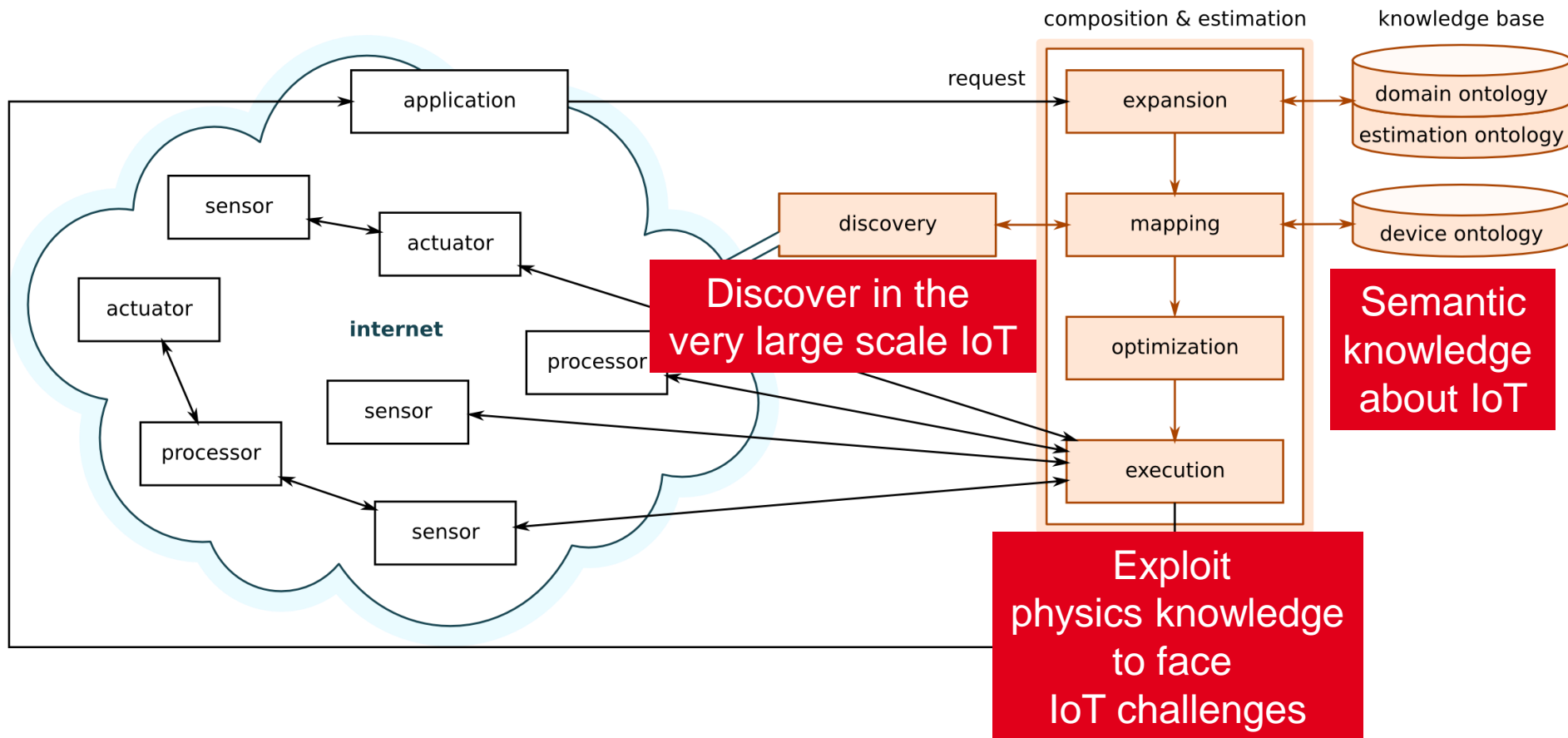
# State of the Art: But IoT Challenges Largely Unsolved (2)

- Facing Unknown environment
  - Applies traditional dynamic service/resource discovery protocols
  - But existing protocols mostly intended at small to medium-scale networks
  
- Facing Concurrent access
  - Mostly unexplored
  - Relevant study in the HCI domain
  - Adequate policies to be devised

# Toward facing the IoT Challenges: Physics to the Rescue

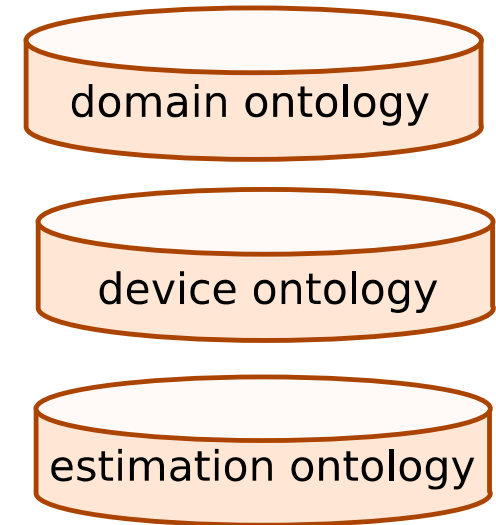
- The IoT is physical
    - Properties in the physical world are highly correlated, highly continuous in space/time, and very often predictable
  - Tools in our arsenal
    - Approximation, estimation
    - Probability models
    - Composition
- But right now it takes a field expert to make use of these tools
- Automate the process through the extensive use of semantic information

# Toward a Middleware Architecture: Focus on Scale and Unknown Environment



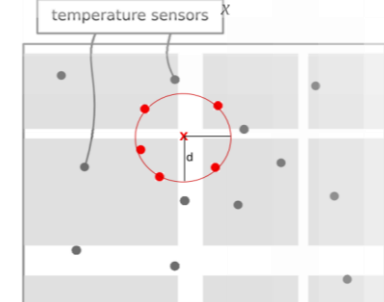
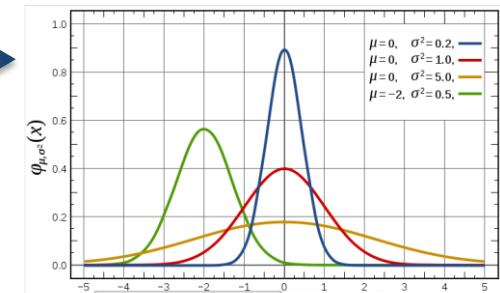
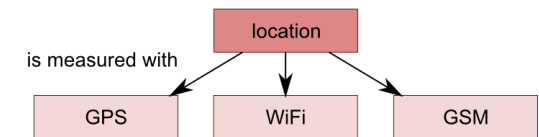
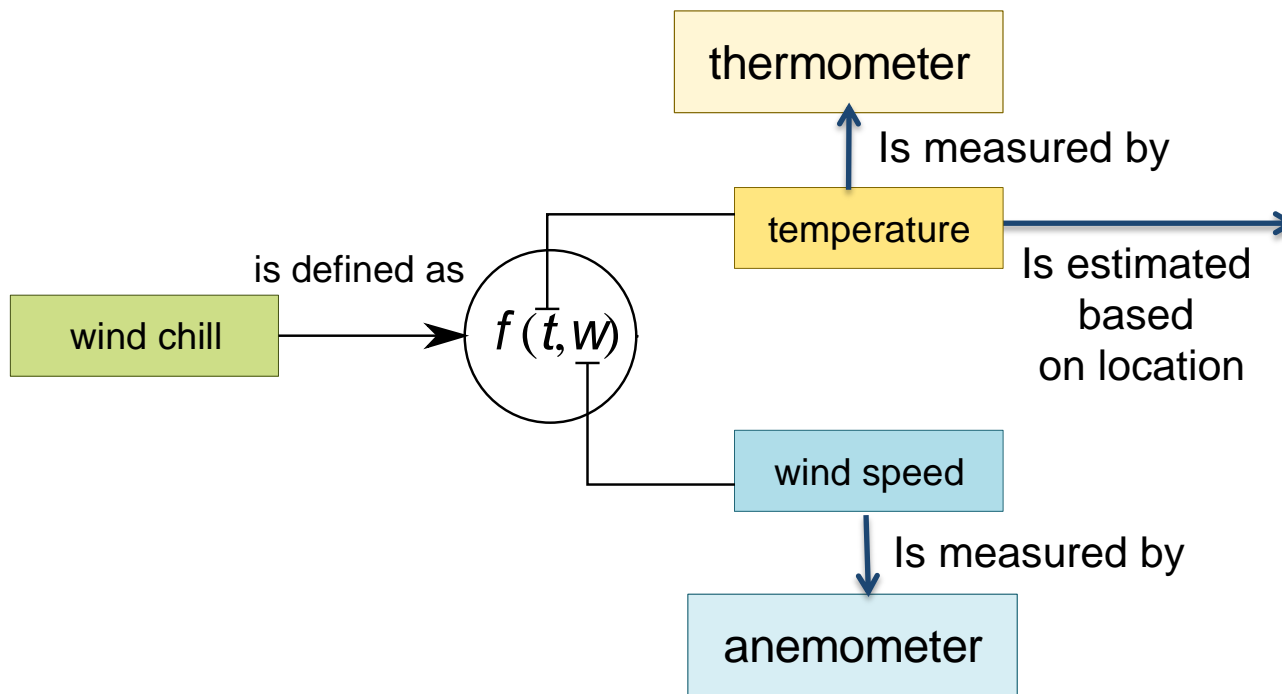
# The Knowledge Base: 3 Ontologies

- **Domain ontology**
  - Describes physical concepts
- **Device ontology**
  - Describes sensors and actuators
- **Estimation ontology**
  - Describes probabilistic models, etc.

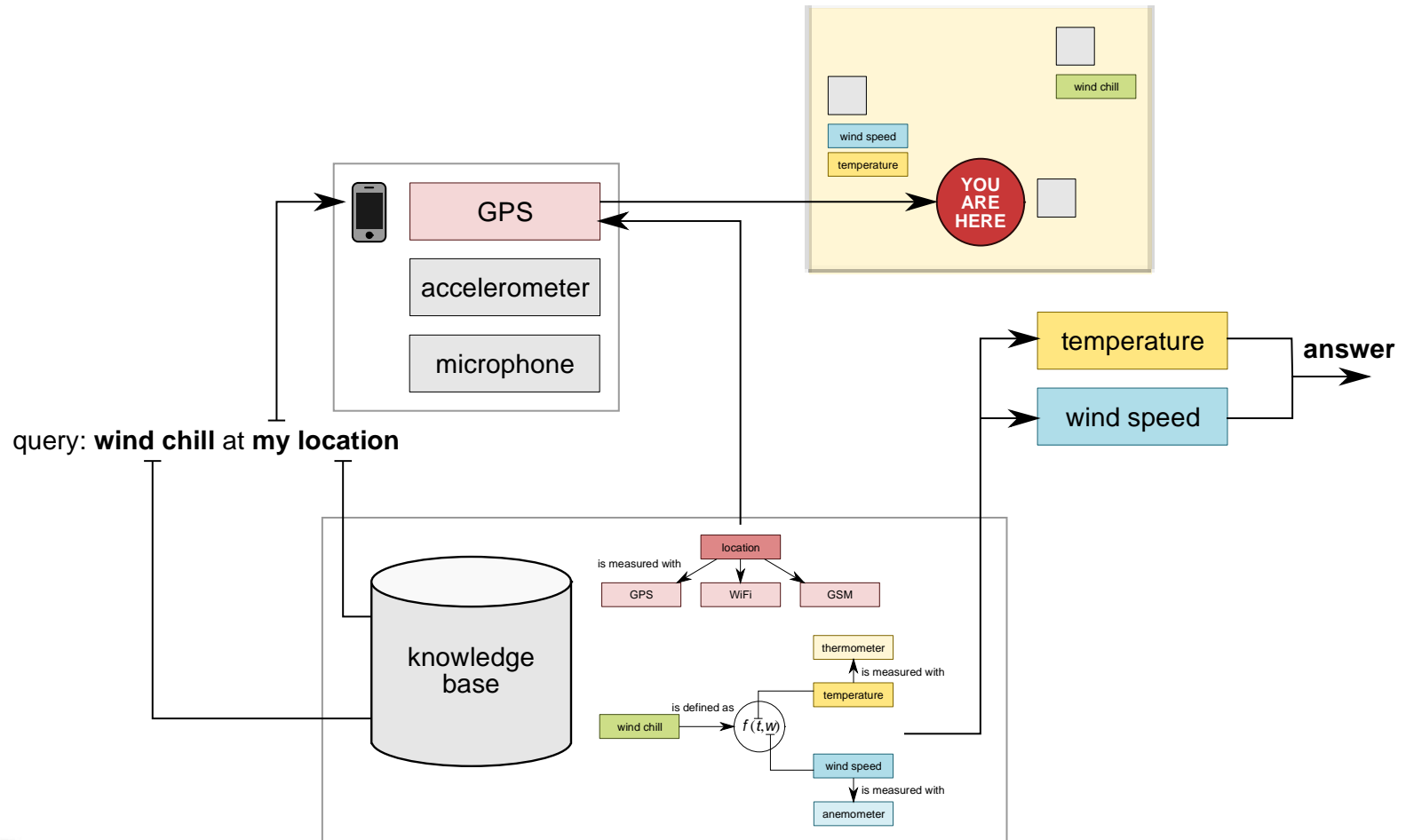


# The Knowledge Base: Example – *Wind chill at a Location*

- domain ontology
- device ontology
- estimation ontology

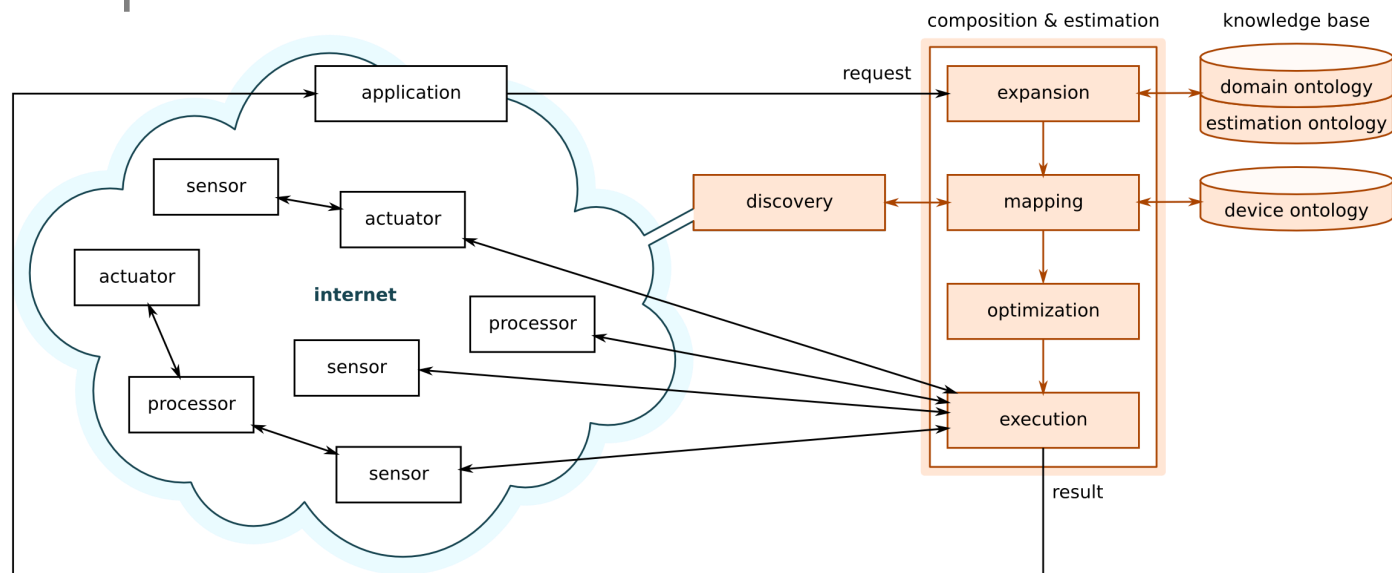


# Service Composition: Expand query using the Knowledge Base



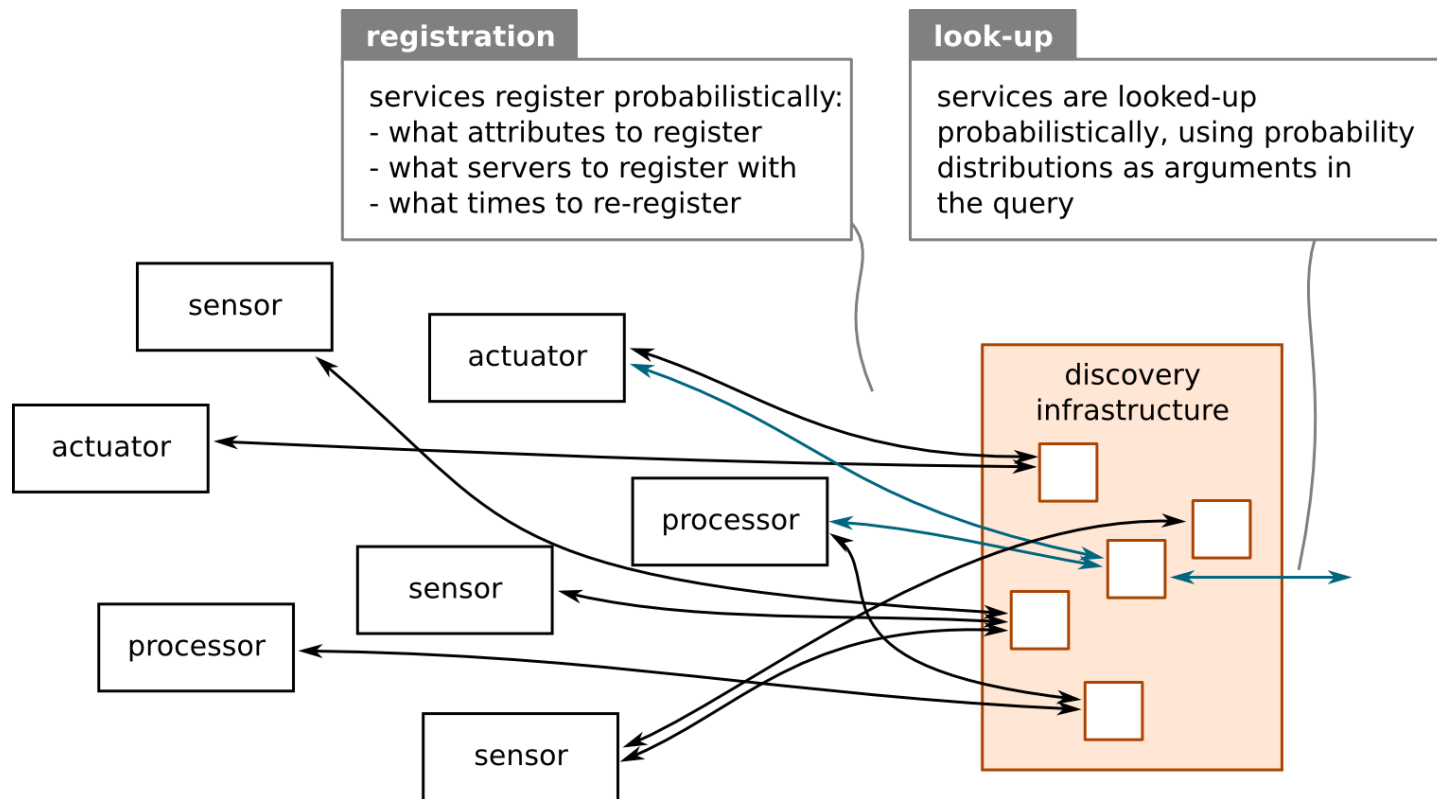
# But Large Scale Breaks Composition

- Service composition becomes infeasible when there are too many alternative services
- **Smart composition:** Select most effective composition wrt the environment



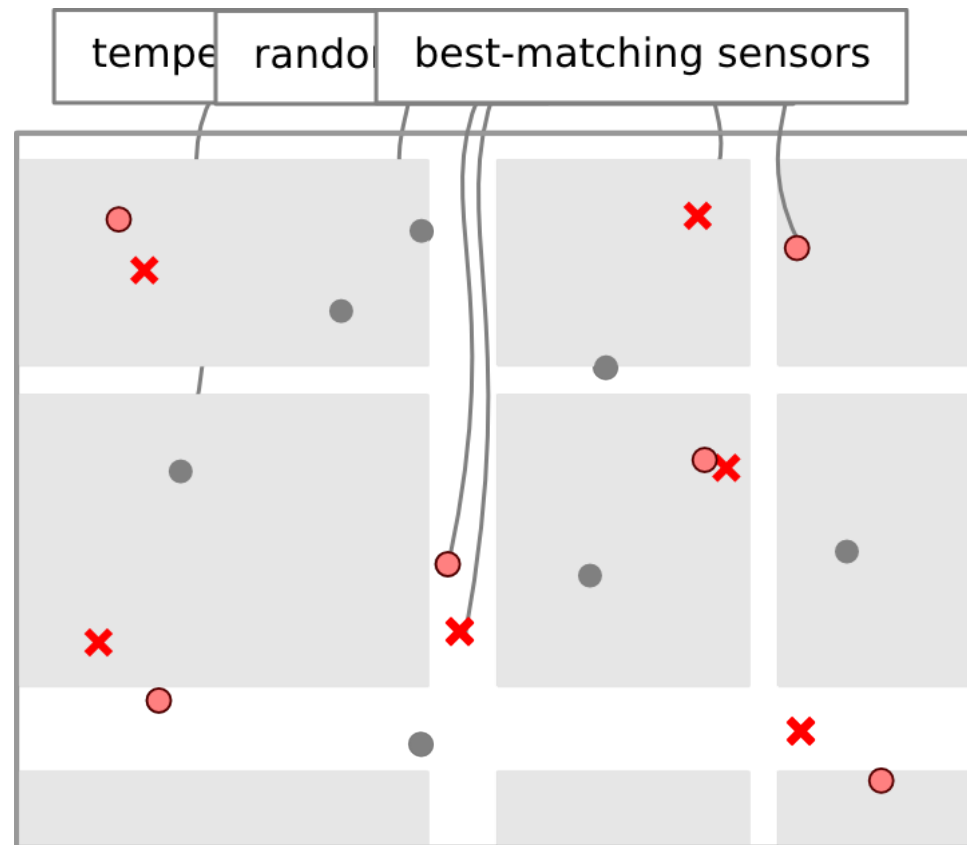
# Also Addressing Scale: Probabilistic Discovery

- 2 Parts: Registration & Lookup



# Also Addressing Scale: Probabilistic Lookup

## Example – Average Temperature in Paris

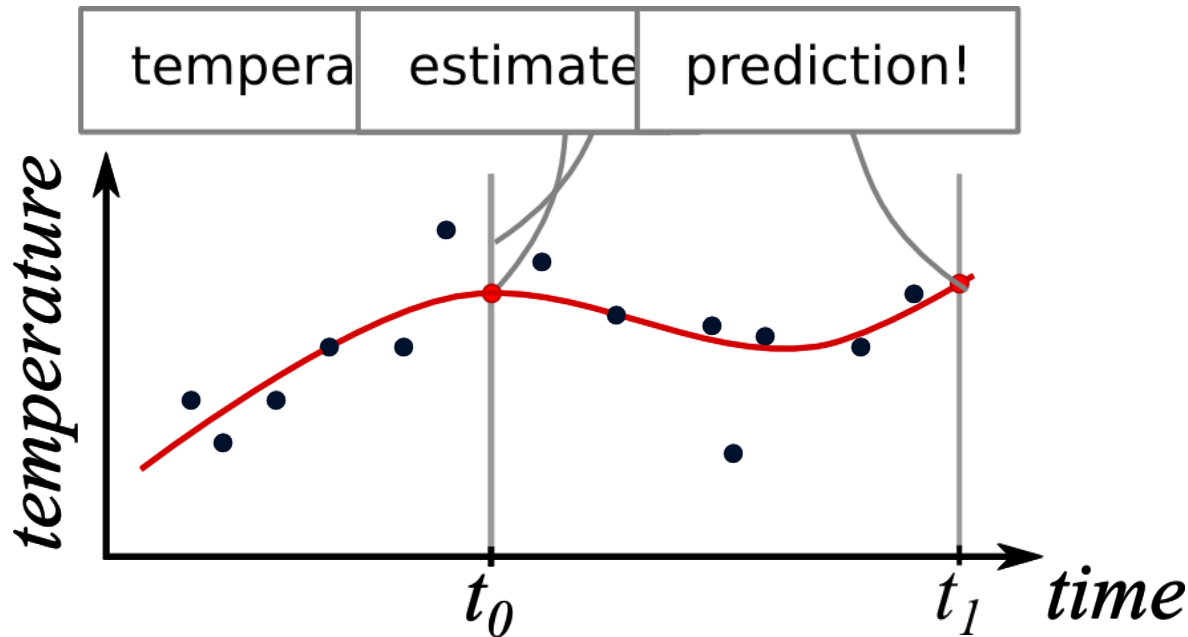


# Addressing Missing Data: Estimation

- User may want a data-point that is not present in the collected data
  - Estimate it!

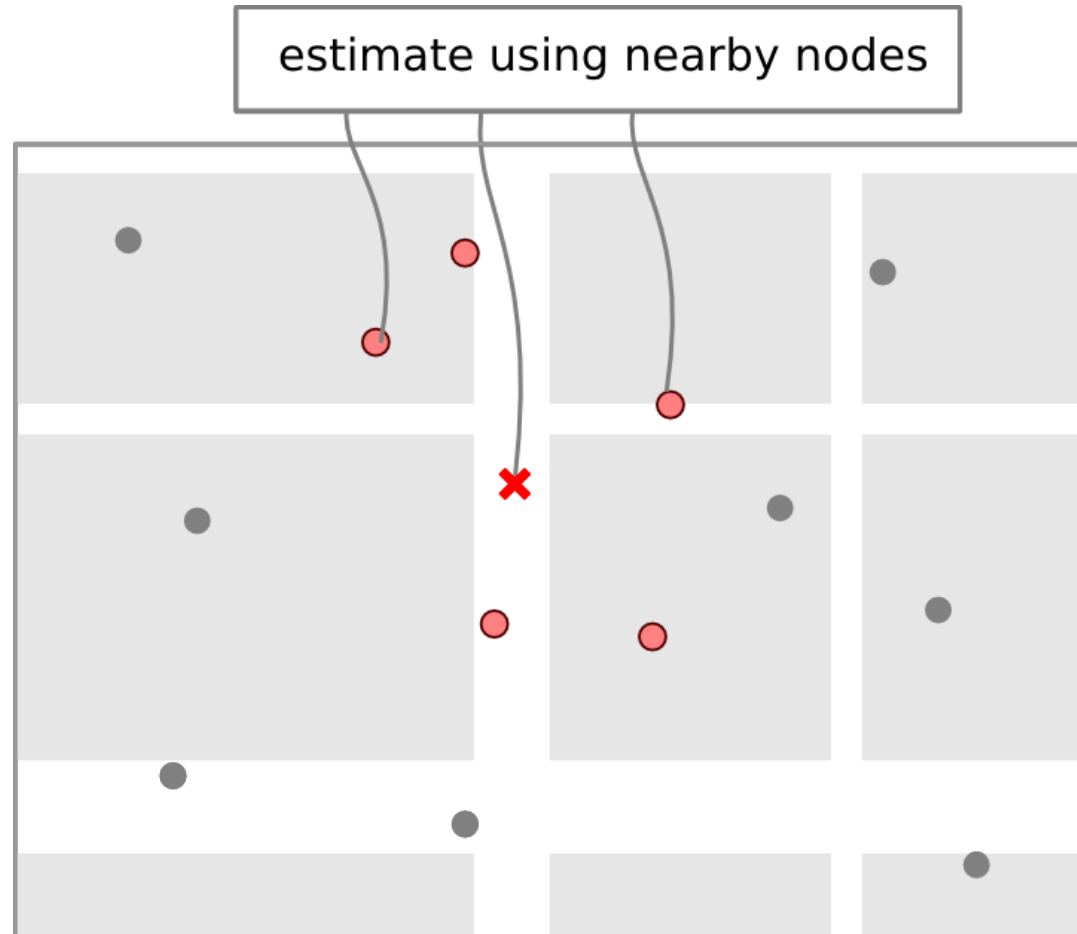
# Addressing Missing Data: Estimation

## Example - Missing data point



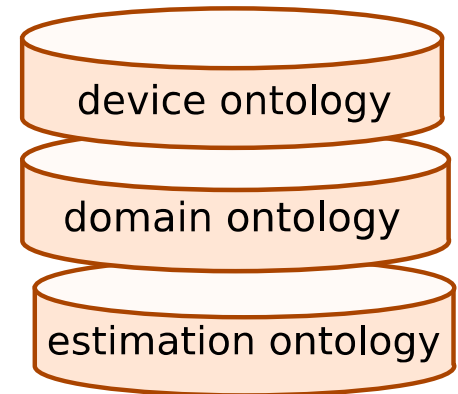
# Addressing Missing Data: Estimation

## Example – Missing data source



## Conclusion – Wrap up

- We can make use of physical properties to address several challenges of the IoT
- Rely on ontology knowledge
- Status
  - Started the ontologies...
  - ... created an abstraction for sensors
  - ... and already have a mobile phone middleware to test-drive proposed abstraction



# Conclusion – What's next

- Much ahead of us...
  - Smart composition
  - Probabilistic registration and lookup
  - Heterogeneous service access
  - ...

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# Thank you

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