Simulation of IoT to Boost Services Interoperability and Lower Barriers for Things Integration

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Why do we care?

- 25 billion connected things by 2020
- The connected kitchen will contribute at least 15% savings in the food and beverage industry by 2020
- Through 2018, there will be no dominant IoT ecosystem platform; IT leaders will still need to compose solutions from multiple providers

Typical consumer’s activities and corresponding consumer’s needs

Consumer’s need	Consumer’s ask
Clothes	A fresh shirt availability upon leaving from home
Duties/routines	Check items against check-list for vacation
Food and drinks	Dinner components are available in the fridge?
Microclimate	Set a desired temperature in a car
Transportation	Is fuel enough in a tank to get to desired destination?
Transportation	Probability of parking lot availability at destination
Transportation	Advise an optimal transport/route
Food and drinks	Ice cream offerings from vendors nearby
Duties/routines	Switch-off lights and lock the door when leaving
Food and drinks	While shopping, assistance with in-store navigation

Unlock IoT potential for consumers:

- Consumer’s needs satisfied on time
- More comfort for consumer
- Optimal way of consumer’s needs satisfaction
- Automation of consumer’s routines/duties

Executive summary

Talk suggests directions for further development of global IoT

What: Unlock IoT potential to assist consumers daily

How: Introduce a scalable model of IoT interoperability, then

- Software simulation of IoT universe allowing
  - Validation and debugging of a given IoT interoperability model
  - Experiments with adding random capabilities to IoT entities
  - Simulation-inspired ideas for features of new IoT entities
  - Validation of new IoT entities design and integration into IoT

Scalable Model of IoT Interoperability

Key IoT scalability challenges

- Integration of new IoT entity with random capabilities into IoT
- Complex interoperability scenarios between random IoT entities
- Evolution of Model's components to account for new challenges
- Fast-time-to-market and low-to-no-barriers for all participants
- Consumers are not locked into an ecosystem of a particular vendor
- Major security and privacy concerns

Lot's of efforts to address key challenges

Transport: IoTivity project by Open Interconnect Consortium

Organize IoT entities in the networks, registration mechanism, functionality discovery, state observation and manipulation. It also solves a number of security issues.

Semantics: W3C's Semantic Web technology stack

Facts are expressed in triples: {subject, predicate, object}
A set of such triples is RDF graph capturing relations between different entities and in this way expressing semantics of a world.

Forums and efforts

W3C Web of Things Working Group
Google, Microsoft, Yahoo and Yandex: schema.org
Annual IoT Semantic Interoperability Workshop
Ontology Summit.

No known (de-facto) standards and/or SW stack to address majority of scalability challenges

Let's Put Together An Exemplary IoT Interoperability Model Satisfying Scalability Challenges

Foundation:

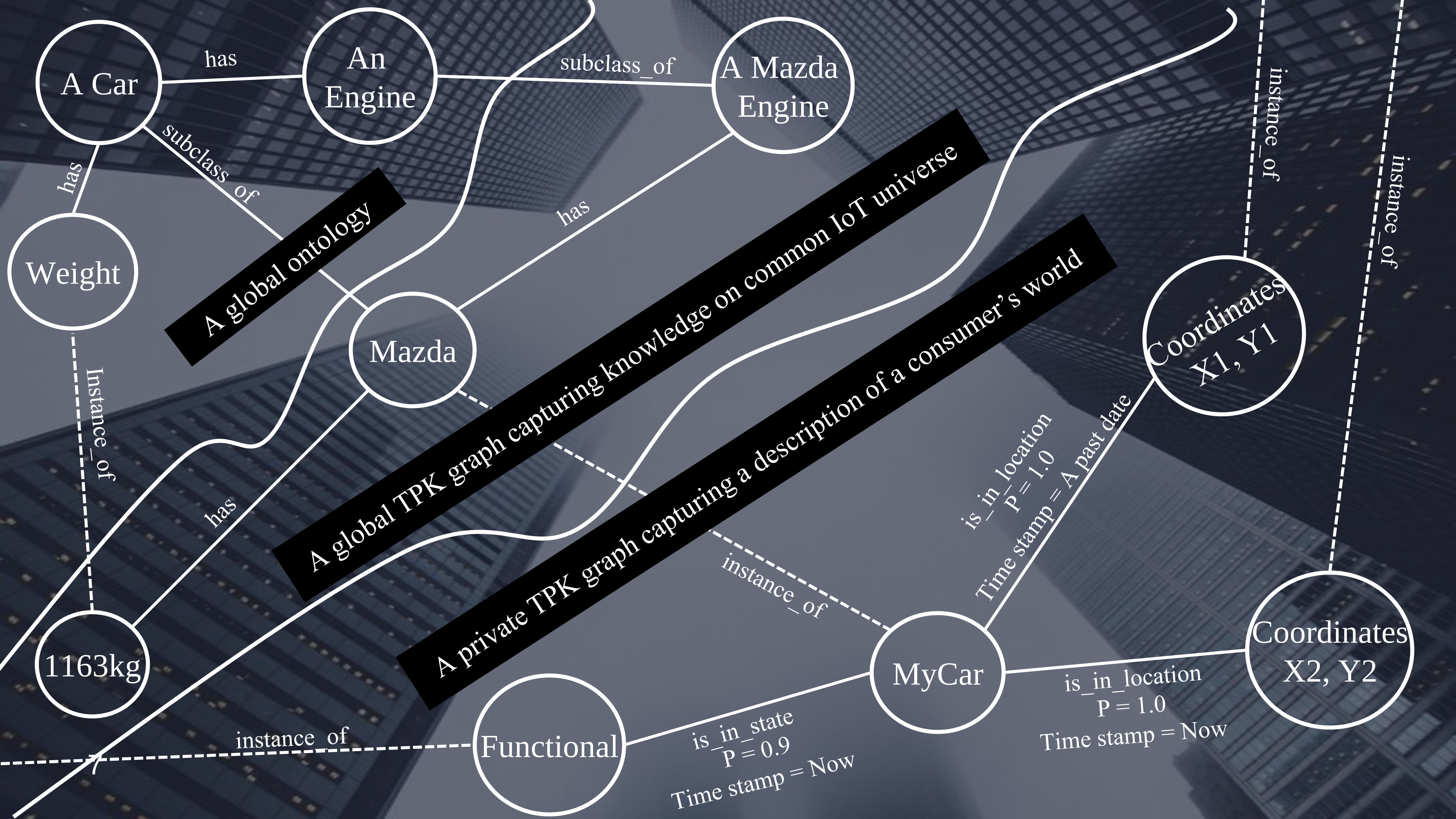
Google Knowledge Vault
Probabilistic approach to the description of relations between objects and subjects in knowledge graph. Allows to express a degree of confidence for accumulated facts.

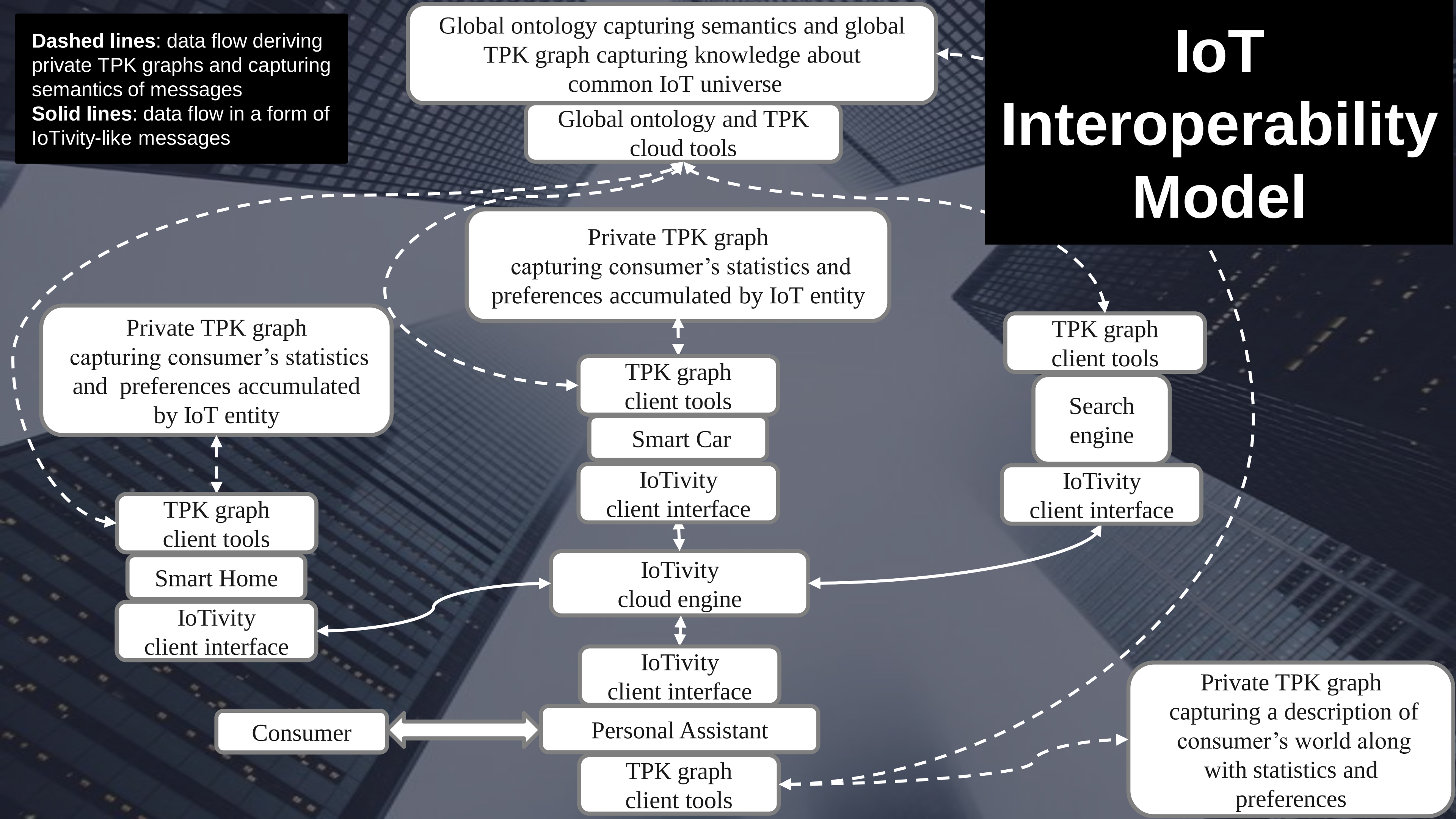
Global ontology
Capturing semantics of IoT universe

Temporal Probabilistic Graph (TPK)
An extension to Knowledge Vault, adding a time stamp to each relation

Temporal Probabilistic Knowledge graphs
Capturing global and private knowledge using global ontology

Interoperability ensured since all IoT communications happen using common language


A Car
has
An Engine
subclass_of
A Mazda Engine
has
subclass_of
Weight
A global ontology
has
Mazda
A global TPK graph capturing knowledge on common IoT universe
A private TPK graph capturing a description of a consumer's world
Instance_of
has
instance_of
instance_of
instance_of
Coordinates X1, Y1
is_in_location
P = 1.0
Time stamp = A past date
1163kg
MyCar
Coordinates X2, Y2
is_in_location
P = 1.0
Time stamp = Now
instance_of
Functional
is_in_state
P = 0.9
Time stamp = Now


IoT Interoperability Model
Dashed lines: data flow deriving private TPK graphs and capturing semantics of messages
Solid lines: data flow in a form of IoTivity-like messages
Global ontology capturing semantics and global TPK graph capturing knowledge about common IoT universe
Global ontology and TPK cloud tools
Private TPK graph capturing consumer's statistics and preferences accumulated by IoT entity
Private TPK graph capturing consumer's statistics and preferences accumulated by IoT entity
TPK graph client tools
Smart Car
IoTivity client interface
TPK graph client tools
Search engine
IoTivity client interface
TPK graph client tools
Smart Home
IoTivity client interface
IoTivity cloud engine
IoTivity client interface
Consumer
Personal Assistant
TPK graph client tools
Private TPK graph capturing a description of consumer's world along with statistics and preferences

What are the next steps to implement an IoT Interoperability Model?

Simulation of IoT Scenarios

IoT interoperability model design and implementation is a complicated task: a model includes a number of elements and scenarios

There is a need to validate its ability to address problems stated in *the list of key IoT scalability challenges* discussed above

In order to bring such efforts at scale a software simulation of IoT universe is the right solution!

Advantages

Reduction of investments and time required to conduct IoT model validation

Experiments with **modeling** of random capabilities for various IoT entities and exposure of corresponding new usage scenarios

Cheap and fast **validation** of design, features of new IoT entities

,,, and comparison of different scenarios aiming to achieve the same goal and uncovering the best one according to some metrics

A Possible Simulator Design

Simulator idea: simulation of each IoT entity behavior required for its normal functioning and its actions to achieve goals they designed for

Software simulator looks like a multi-agent system in which agents have to interact with each other to ensure their normal functioning

Infinite loop for each *IoT entity* in simulated IoT universe {

Generate new states and update *IoT entity Calendar* accordingly

Listen to IoT and respond to incoming queries, update *IoT entity Calendar* as needed

Scan *IoT entity Calendar* and update *IoT entity Conditional Capabilities*

Scan *IoT entity Conditional Set of Needs* and initiate appropriate queries from *IoT entity Queries*

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New Entities Prototyping and Integartion

Failure to uncover issues with certain features and behavious of new IoT entity before integration into real IoT may cause undesired consumer's experience and even failure of other IoT entities interacting with new IoT entity

How to help a vendor with new IoT entity prototyping and integration into *existing* IoT ?

Answer: Lightweight simulation of queries to IoT entity allowing to validate:

Syntactic and semantic correcteness of IoT entity interoperability with IoT universe

IoT entity declared capabilites

IoT entity context intellegence

IoT entity self-maintanence and self-recovery capabilities

IoT entity security and safety

Summary

Draft and implement a model of IoT interoperability

Implement a software simulator according to the model

Run simulation: validate the model, experiment with adding random capabilities to IoT entities and expose new usage scenarios, validate scenarios for integration of new IoT entities

A Problem of Intelligence Distribution Across IoT

Serving queries in global IoT
How to find best IoT entity to handle your task?

Extend existing web search engines

Crawling the IoT to get up-to-date picture of IoT entities available and their basic functionality

Pre-indexing of data found during crawling step to ensure fast search

Search engines to handle queries sent via IoTivity-like stack using global ontology and global TPK graph as a semantics notion

Two extremes:

An IoT entity is smart enough to ensure its normal functioning and achieve its goals even if interoperability with the other IoT entities is required

An IoT entity can just report its status and don’t talk to the rest of IoT if help is required to serve an incoming query

Flexibility:

Some IoT entities should be more intelligent and some less
Consumer controls what to delegate to particular IoT entities
IoT entity vendors differentiate by offering their own way to solve a particular task
IoT may have special *orchestrators* with extra intelligence to govern complicated tasks involving interoperability scenarios with several IoT entities