16.12.2021

The Data Management Perspective in the Internet-of-Things

5th International Conference on Computational Intelligence, Cyber Security and Computational Models (ICC3 - 2021)

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https://www.ifis.uni-luebeck.de/index.php?id=groppe

Stations of my academic life

Trying to impress (not sure if it's working)...

- $>$ 120 publications
  - 94 co-authors
  - 42 publications (33%) are co-authored by bachelor/master students (being students at time of writing)
- 2 supervised dissertations, 3 current PhD students
- $\approx$ 85 bachelor/master/diploma thesis/student projects
- $\approx$ 60 contributors to LUPOSDATE
- $>$ 37 lectures, in the areas of
  - Semantic Web
  - Cloud- and Web-Technologies
  - Mobile and Distributed Databases
  - Databases
  - Algorithms and Datastructures
  - Compiler

Trying to impress (not sure if it's working)...

- 8 third-party fundings ($\approx$ € 2M)
- Scientific Services
  - Workshop Chairs
    - Semantic Big Data (SBD) @ SIGMOD (2016 - 2020)
    - Big Data in Emergent Distributed Environments (BiDEDE) @ SIGMOD (2021 - 2021)
    - Very Large Internet of Things (VLIoT) @ VLDB (2017 - 2021)
    - Web Data Processing and Reasoning (WDPAR) @ KI 2018
  - General Chair
    - International Semantic Intelligence Conference (ISIC) 2021 - 2022
  - many other scientific services
    - $\approx$ 92 PC memberships
    - reviewer of $\approx$ 30 journals
    - editor of 3 journals

Trying to impress (not sure if it's working)...

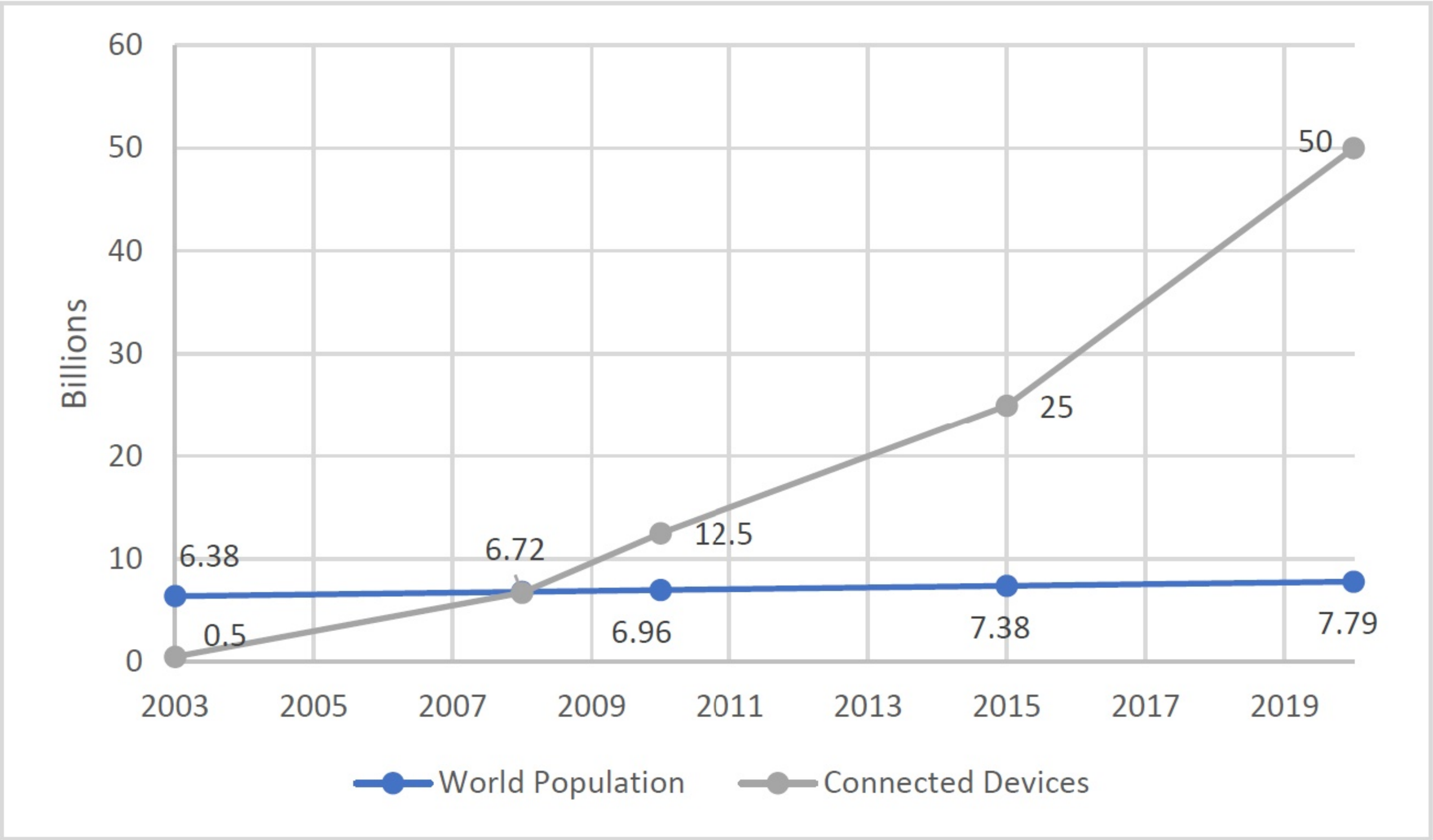
Detailed Information available at
https://www.ifis.uni-luebeck.de/~groppe

Definitions of Internet-of-Things (IoT)

- Internet is extended by adding things as network nodes.
  - connect those physical objects that are not yet connected with the help of the Internet and
  - thus create significant added value[1]
    - a better collaboration between humans and machines through new types of applications in various areas.
    - Application domains like Smart City, Smart Healthcare, Smart Farming, Smart Factory, ...
- "IoT allows people and things to be connected Anytime, Anyplace, Anything and Anyone ideally using any path/network and Any service."[2]

[1] Hanes et al., IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Things. 1st ed. Cisco Press, 2017
[2] Guillemin, P. and Friess, P. Internet of Things: Strategic Research Roadmap. Tech. rep. Oct. 2009.

CISCO: Age of IoT emerged between 2008 and 2009



Things in IoT are heterogeneous

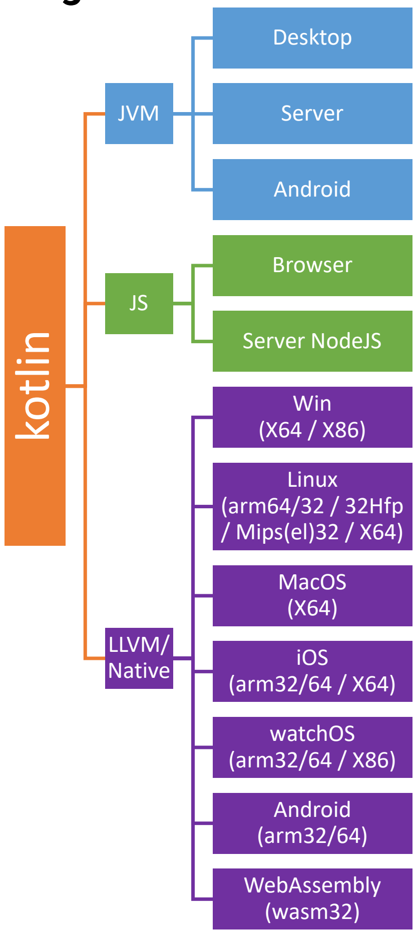
- Different kinds of devices: Smartphone/-watch-/tv/..., sensors, routers, tablets, raspberry pi (and similar), ...
- Hardware (e.g. CPU)
- Operating system (OS)
- Network protocols
- Capabilities
    - Performance of CPU
    - Storage capacity
    - Access to networks (wireless, stationary, ...)
    - ...
- ...

Multi-Platform Development (e.g. of DBMS)

- Native Binaries via C/C++
  - support of a new platform: porting code is necessary
  - code close to hardware, fast execution
  - direct access to native libraries
  - doesn't run in browser
  - most server DBMS: C/C++ code
- Java/Java Virtual Machine (JVM)
  - runs on many platforms (without porting code)
  - interpreted bytecode, via Just-In-Time compilation comparable speed to native execution
  - no direct access to native libraries
  - does neither run on iPhone nor in browser
  - many NoSQL/NewSQL/Cloud DBMS: Java (or JVM language like Scala) code
- Code generation for query processing via C/C++ or Janino-Compiler (JVM)

Multi-Platform Development with Kotlin

Targets:



- Most target platforms are supported
- Splitting the project in platform-**in**dependent and platform-dependent code
  - Platform-dependent code can be partly coded in the programming language of the target platform (e.g., Java for JVM, JS for Web)
- Enables one code repository for various target platforms
  - Sharing of code between server & (various) clients
- Avoids efforts to port code (into other programming languages)

Multi-Platform Development with Kotlin

- Common Module
  - Code independent of platforms containing declarations for platform dependent code without implementation, e.g.:

```
expect fun formatString(source: String, vararg args: Any): String
expect annotation class Test
```

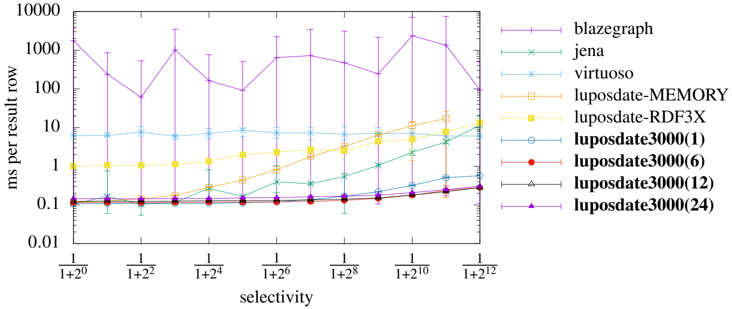
- Platform Module
  - Implementation of within the common module declared platform-dependent code (and other platform-dependent code), e.g.:

```
actual fun formatString(source: String, vararg args: Any) =
                                             String.format(source, args)
actual typealias Test = org.junit.Test
```

- Regular Module
  - depend on platform modules or platform modules depend on this module
- **However: High compilation times**, **faster**: Including different sets of source code directories for different targets and configurations (e.g., centralized, Cloud, P2P, browser, ...)

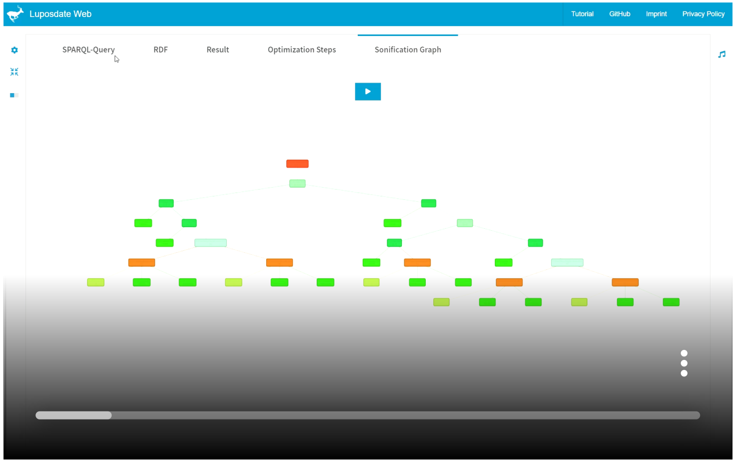
The Power of Multi-Platform: LUPOSDATE3000

- ultra-fast in jvm...



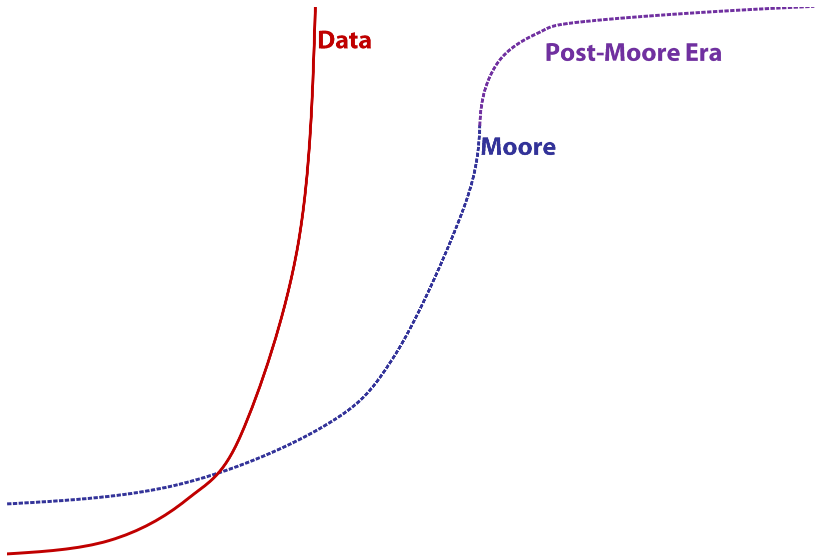
[B. Warnke, M.W. Rehan, S. Fischer, S. Groppe: Flexible data partitioning schemes for parallel merge joins in semantic web queries in: BTW'21]

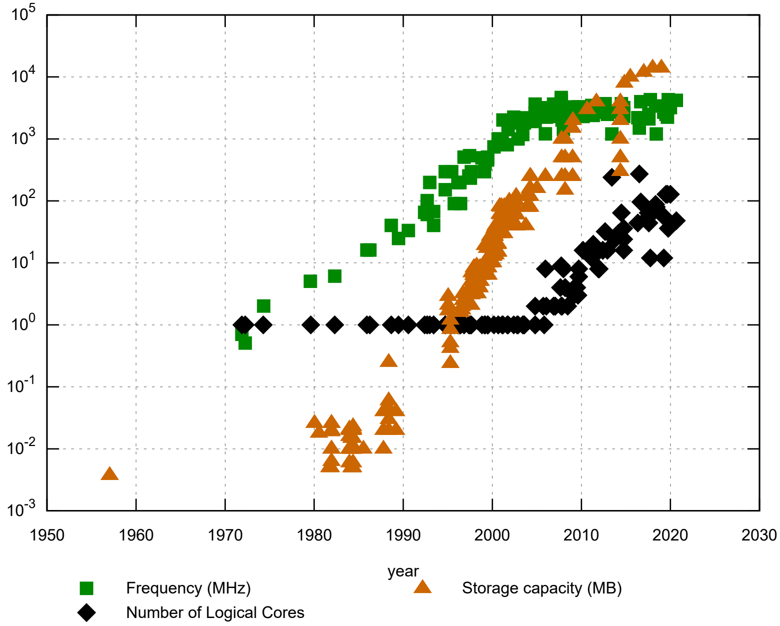
- ...but also enabling web demos running completely in the browser!



[S. Groppe, R. Klinckenberg, B. Warnke. Sound of Databases: Sonification of a Semantic Web Database Engine. PVLDB, 14(12), 2021]

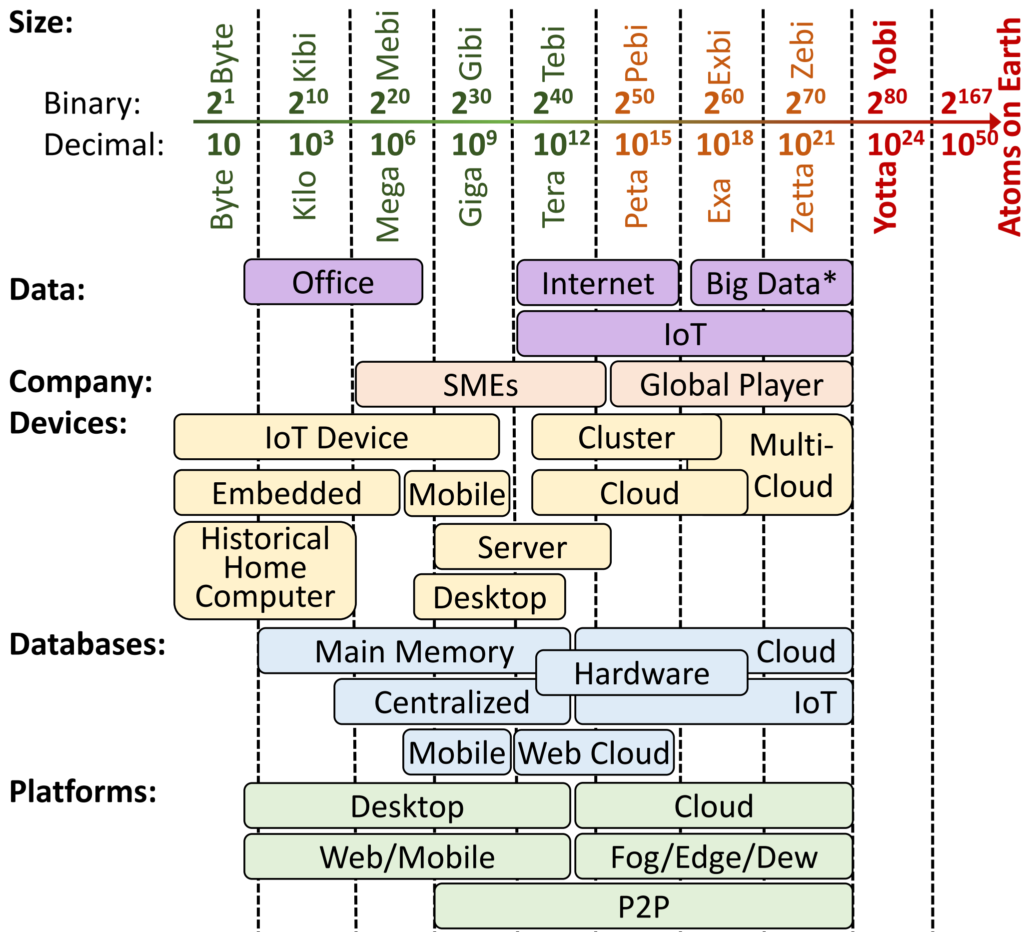
Data versus Moore





- Data sizes are growing faster than computing capacity of single CPU
  ➡ Parallel/distributed computing to overcome limitations of single CPUs

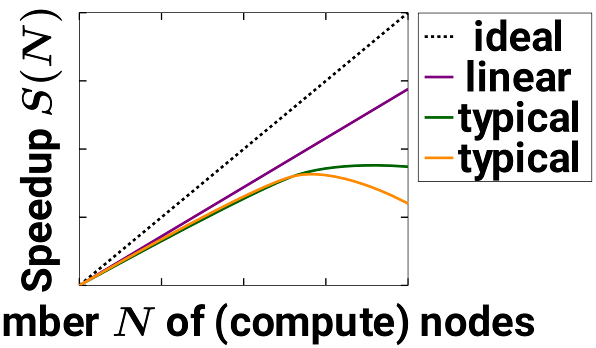
Data Sizes

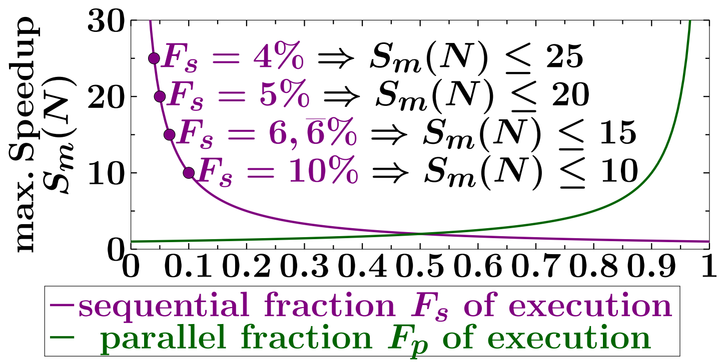


SMEs: Small and medium-sized enterprises * social media, search engines

Amdahl's versus Gustafson‘s law

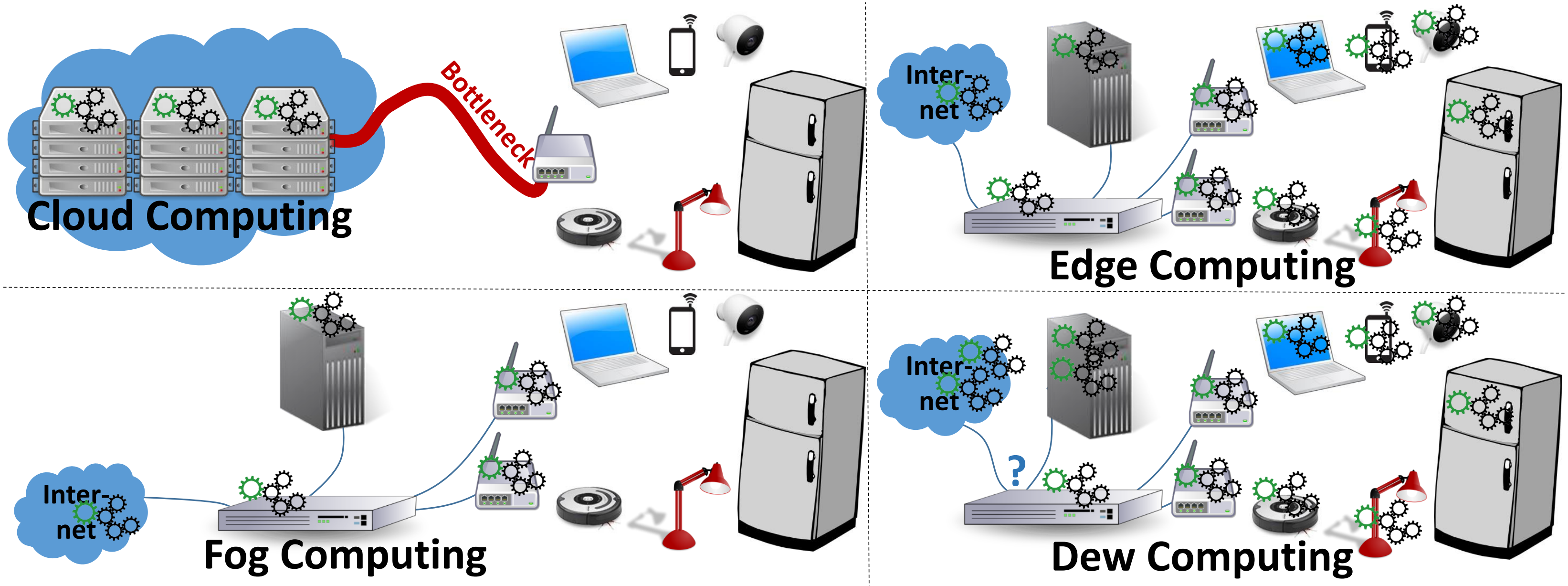
- Amdahl's law
  - a sequential part of the overall algorithm limits overall speedup (in the context of fixed problem/data size)



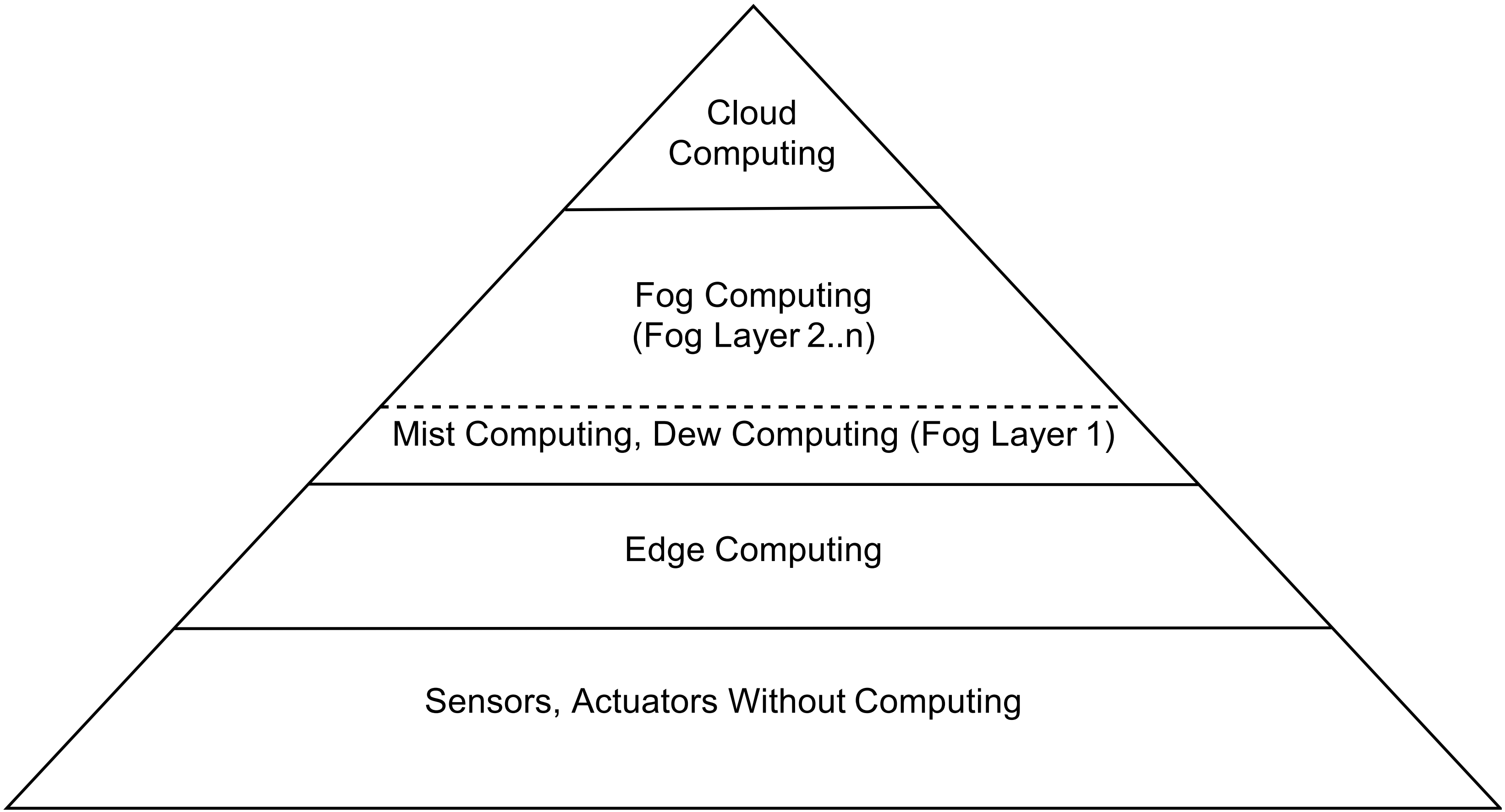


- Gustafson‘s law:
  - programmers tend to set the size of problems to fully exploit the computing power that becomes available as the resources improve
  - if faster equipment or more nodes are available, larger problems can be solved within the same time

Internet-of-Things (IoT) Architectures



Increase in #Devices from Cloud to Edge



Based on P. Varshney, Y. Simmhan, Demystifying Fog Computing: Characterizing Architectures, Applications and Abstractions. ICFEC 2017

Example of an IoT Scenario: Parking Slots

n — WSN of parking sensors that cover parking area n

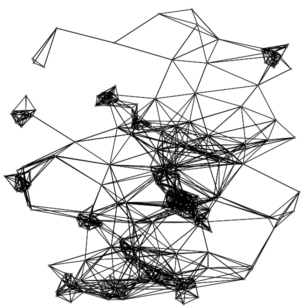
Edge-Node and gateway of the WSN

Fog-Node and gateway to the Internet

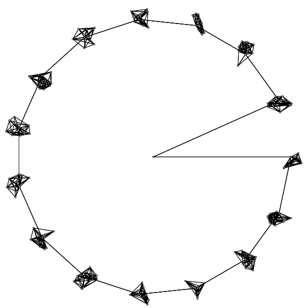
Network Topologies to be considered for IoT query processing

- Scenario: Subnets of sensors of parking slots are connected via different network topologies

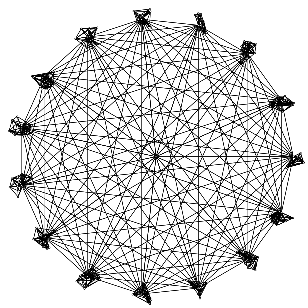
Random:



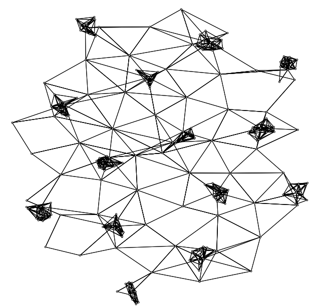
Ring:



Full:



Uniform:



Properties of Routing Algorithms

- Where is the routing performed?

Centralized	Decentralized
one or few central nodes as routers	each and every node is a router
other nodes ask the routers	nodes exchange information

- How fast do routes change?

Static	Dynamic
routes change slowly	routes change more quickly
manual configuration or restart of the routing algorithm	proactive or reactive

- How much information do the routers have?

Global	Local
router node has knowledge of the entire network	no node has knowledge of the entire network
all router nodes have the same view of the network (in a stable state)	node never knows the complete route from a source to a sink

- When is the routing performed?

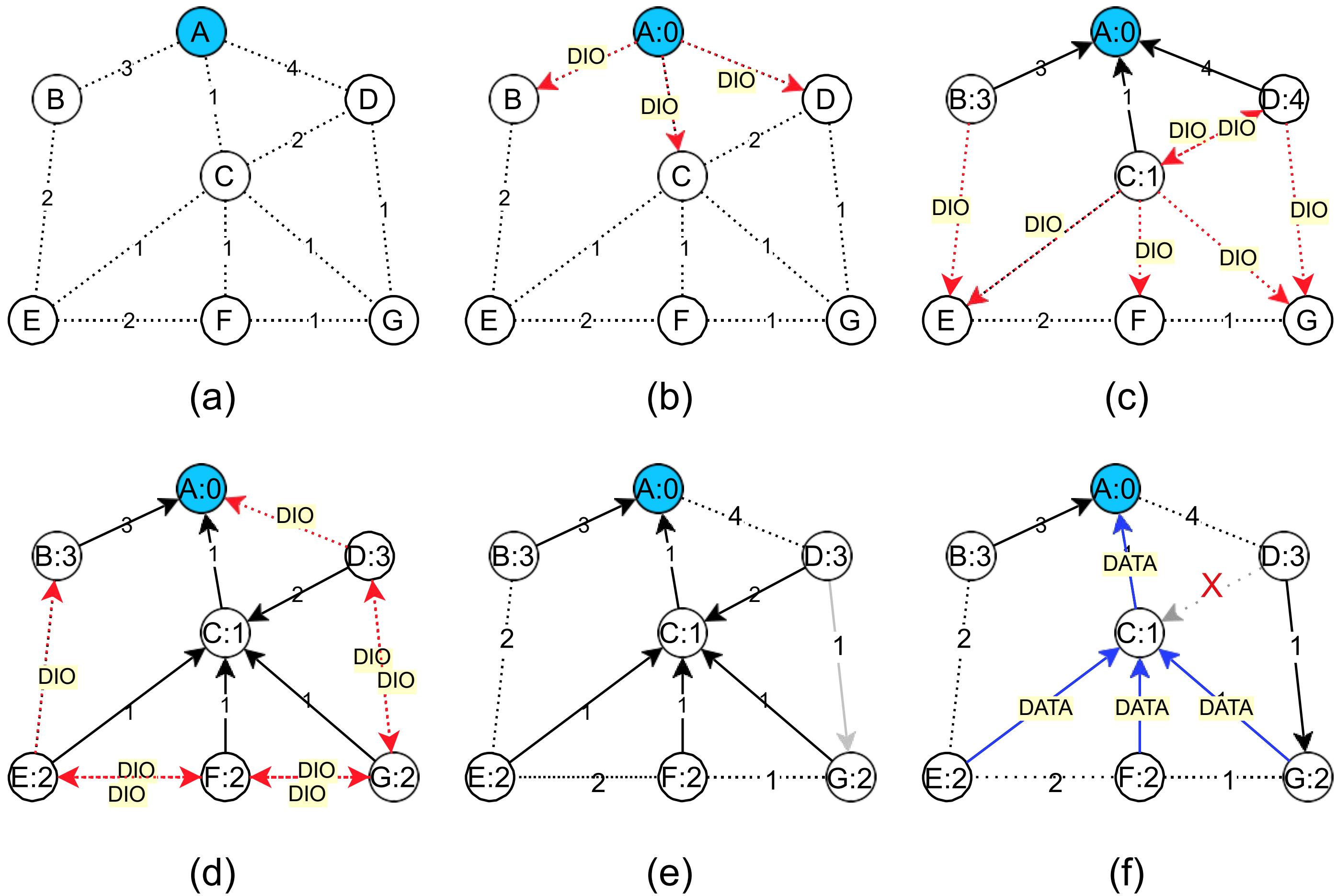
In Advance	On Demand
routing is done before forwarding	routing and forwarding is one mixed process

Routing Protocol for Low-Power and Lossy Networks (RPL)

- Construction of a Destination-Oriented Directed Acyclic Graph (DODAG)
  - via broadcast of DODAG Information Object (DIO) messages
  - similar to a sink tree in which not only the optimal routes, but also alternative routes are permitted
  - alternative routes are to protect against failures or changes in the topology and are only active when required
- Maintenance via a proactive protocol
  - Each DODAG maintains a logical clock
  - When the clock runs out, a DIO broadcast is carried out in order to track down changes in the DODAG
- Routing according to the DODAG

Sobral et al., Routing Protocols for Low Power and Lossy Networks in Internet of Things Applications. Sensors 19(9), 2019

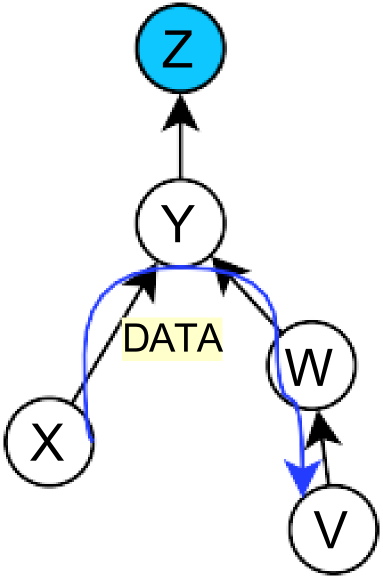
Construction of DODAG



RPL - Routing

Routing Tables and Point-to-Point Traffic in Storing Mode:

Routing Table of Z	
Destination	Next Hop
Y	Y
X	Y
W	Y
V	Y

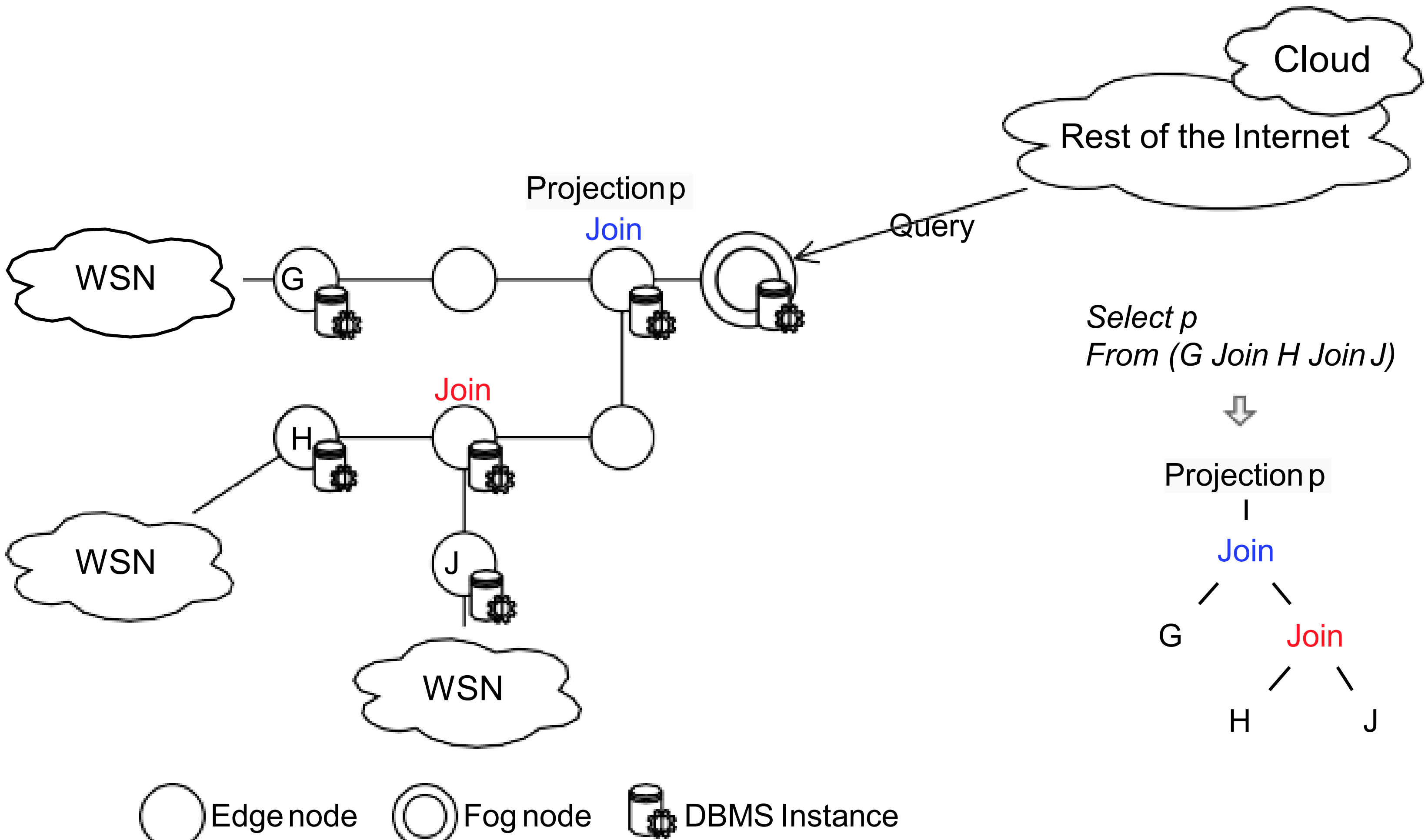


Routing Table of Y	
Destination	Next Hop
X	X
W	W
V	W

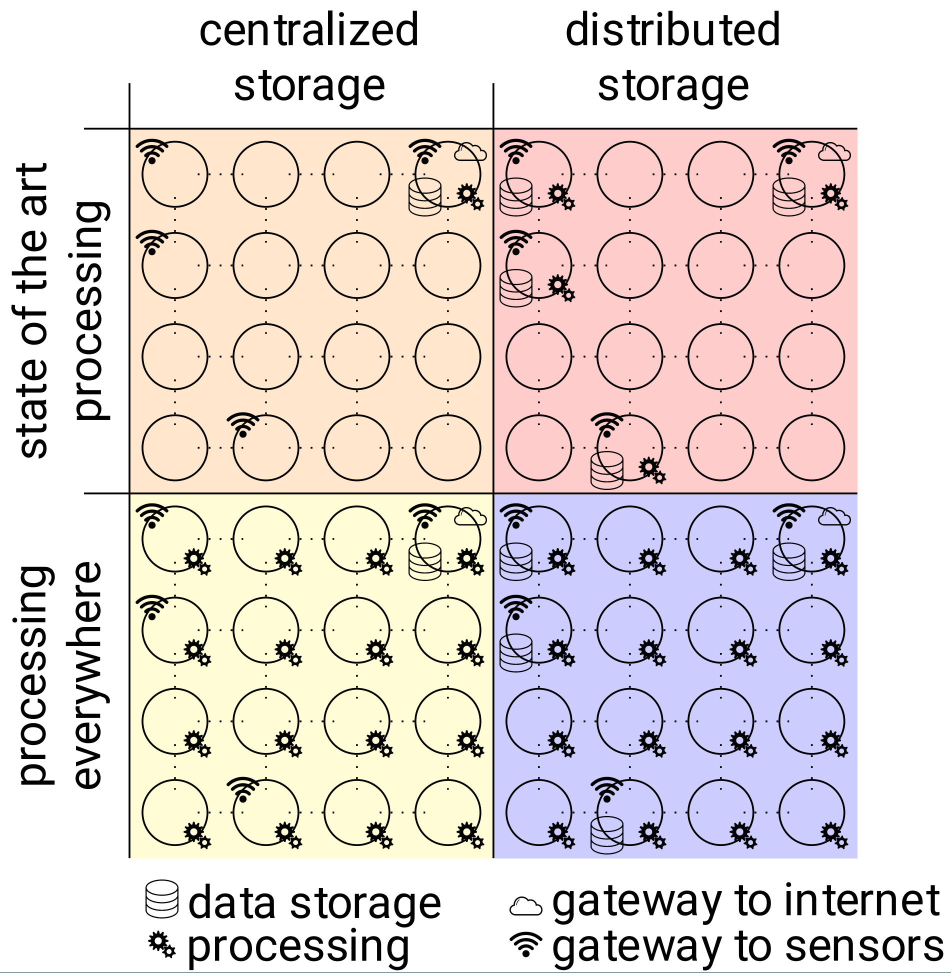
Routing Table of W	
Destination	Next Hop
V	V

Oh, S., Hwang, D., Kim, K., and Kim, K.-H. A hybrid mode to enhance the downward route performance in routing protocol for low power and lossy networks. International Journal of Distributed Sensor Networks 14(4), 2018

Embed Query Execution Plan in Topology

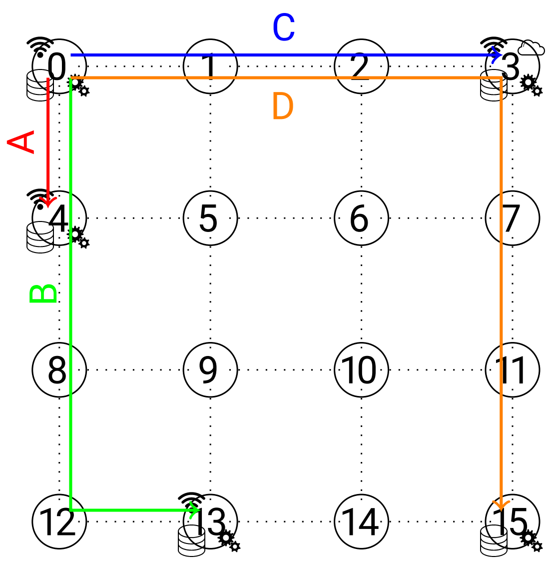


Types of Query Processing in IoT

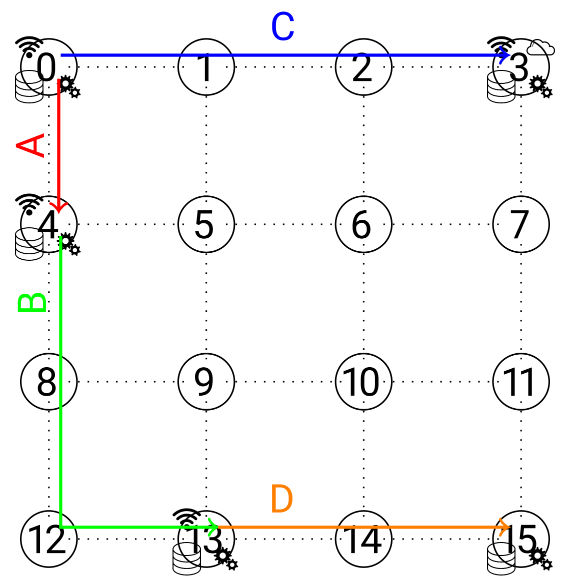


Inserting Data replicated due to indexing scheme

State-of-the-Art:



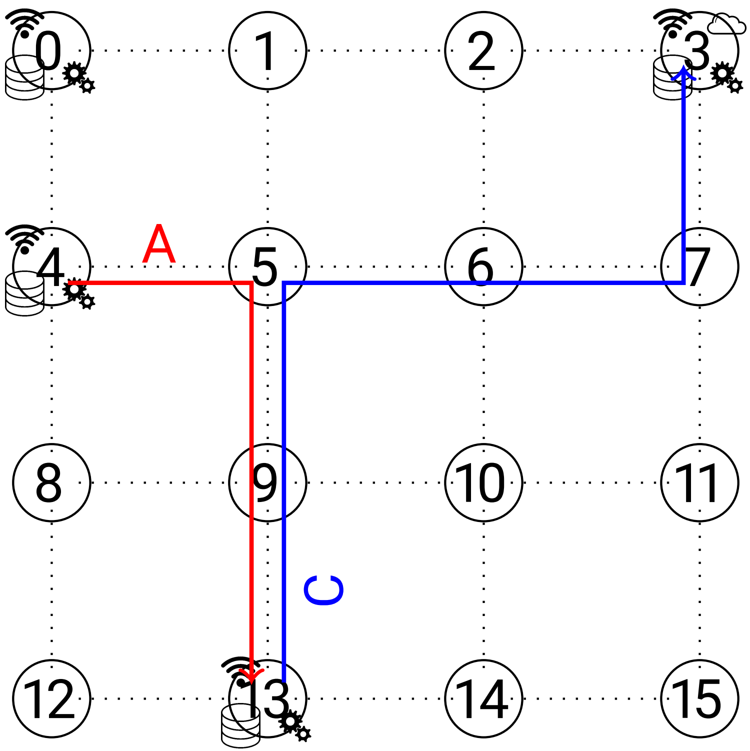
Multi-Cast:



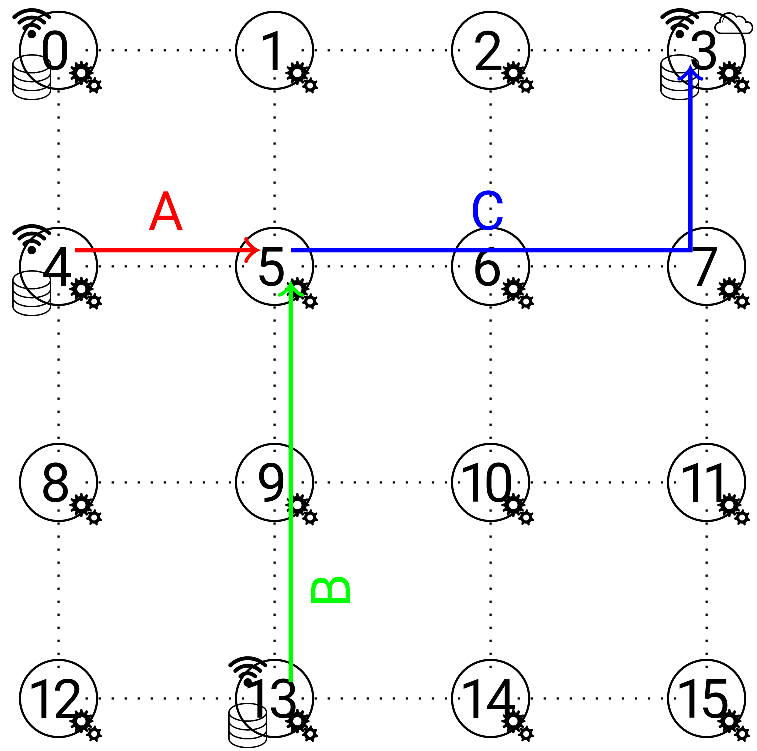
- network traffic reduction during insert by using
  - IPv6 Routing Protocol for Low-Power and Lossy Networks (**RPL**)
    $\longrightarrow$ All-Shortest-Paths (**ASP**): **17-48%**
  - **multi-cast**: **24%**
  - **additional devices**: **3%**

Querying Data in IoT $(4 \bowtie 13 \rightarrow 3)$

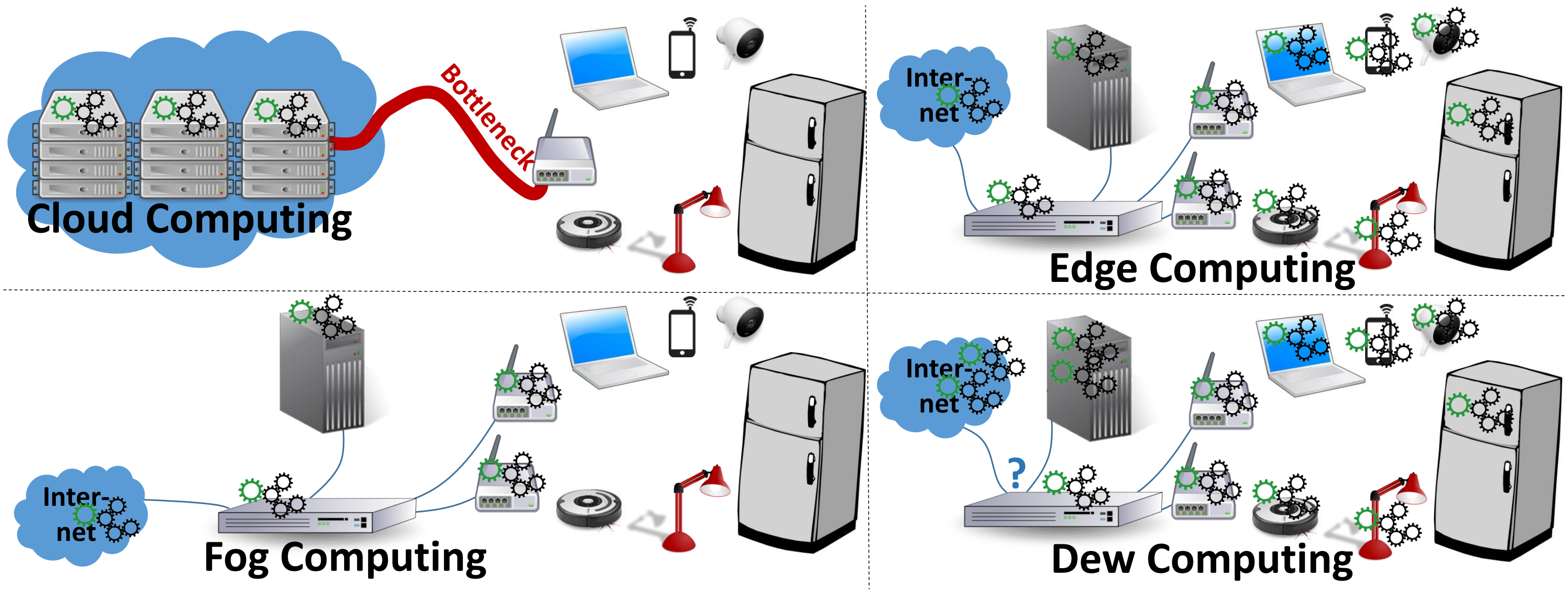
State-of-the-Art:



Combining Routing & Processing:

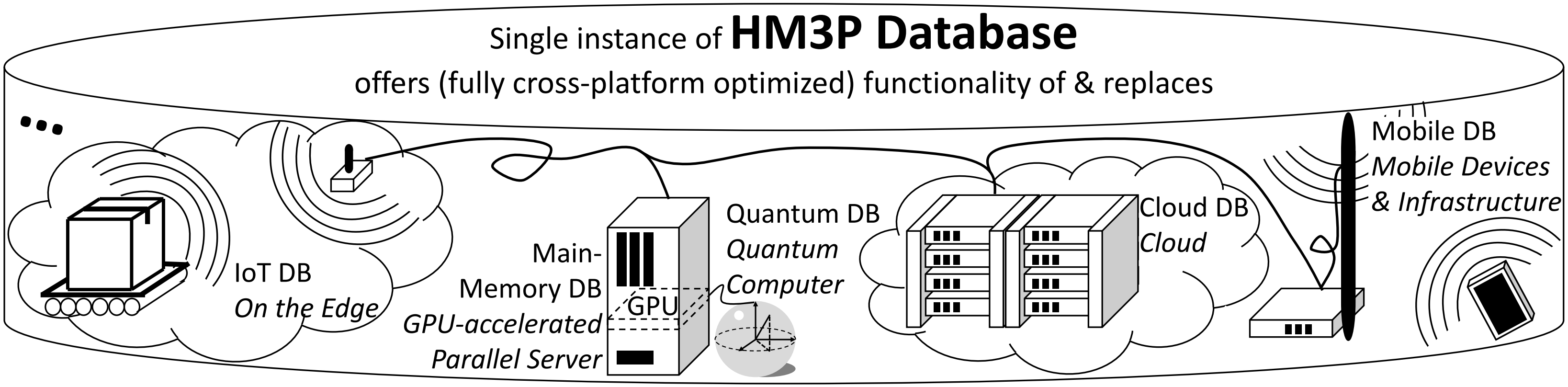


IoT and Cloud as Platforms for Processing the IoT DATA



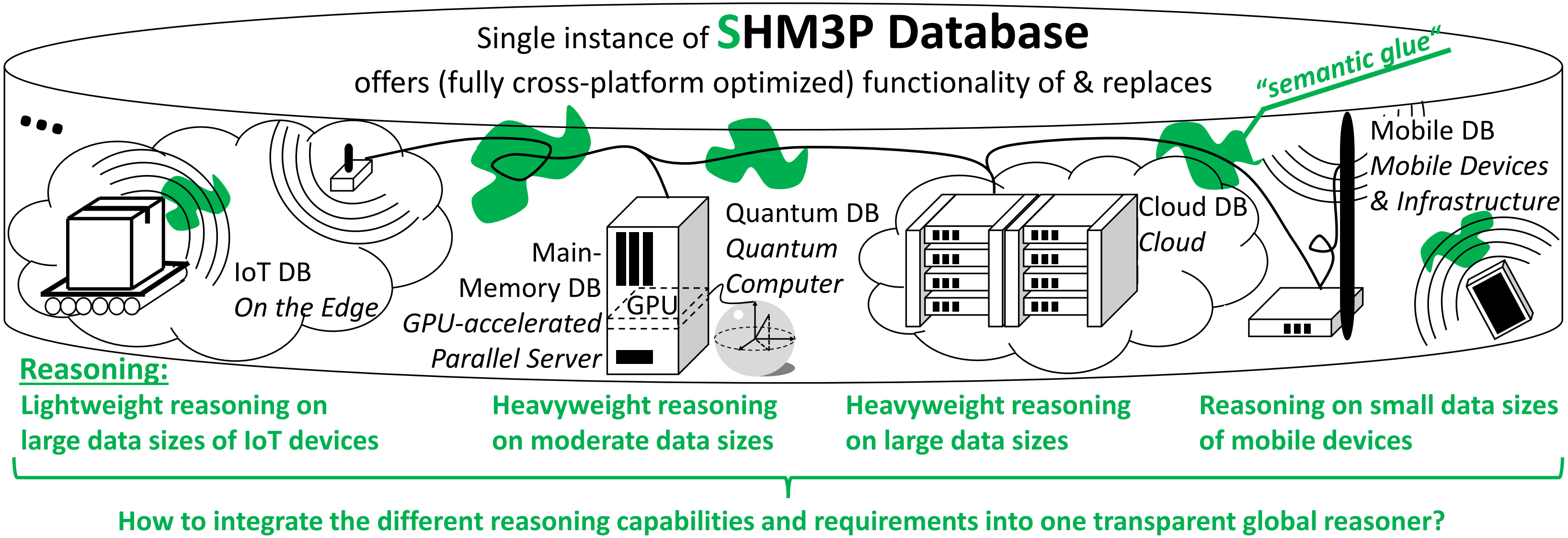
- ...but there are also **other platforms**!

Hybrid Multi-Model Multi-Platform (HM3P) Database



- full and uniform data integration at database level
- performance: fully optimized across different data models
- transparent fault-tolerance
- SQL standards: relational ('87), XML ('03), temporal ('11), JSON ('16), Multi-dimensional Arrays ('19), schemaless ('19), streams ('20?), property graphs ('21?)
- **features of different types of databases running on different platforms can be used**

Variant: Semantic HM3P (SHM3P) DB



- Semantic Layer as glue between other models and platforms
- new challenges like integrating different types of reasoners in a transparent global reasoner

\+ Features of HM3P databases

\+ Easier data integration

\- Performance issues may occur due to semantic layer

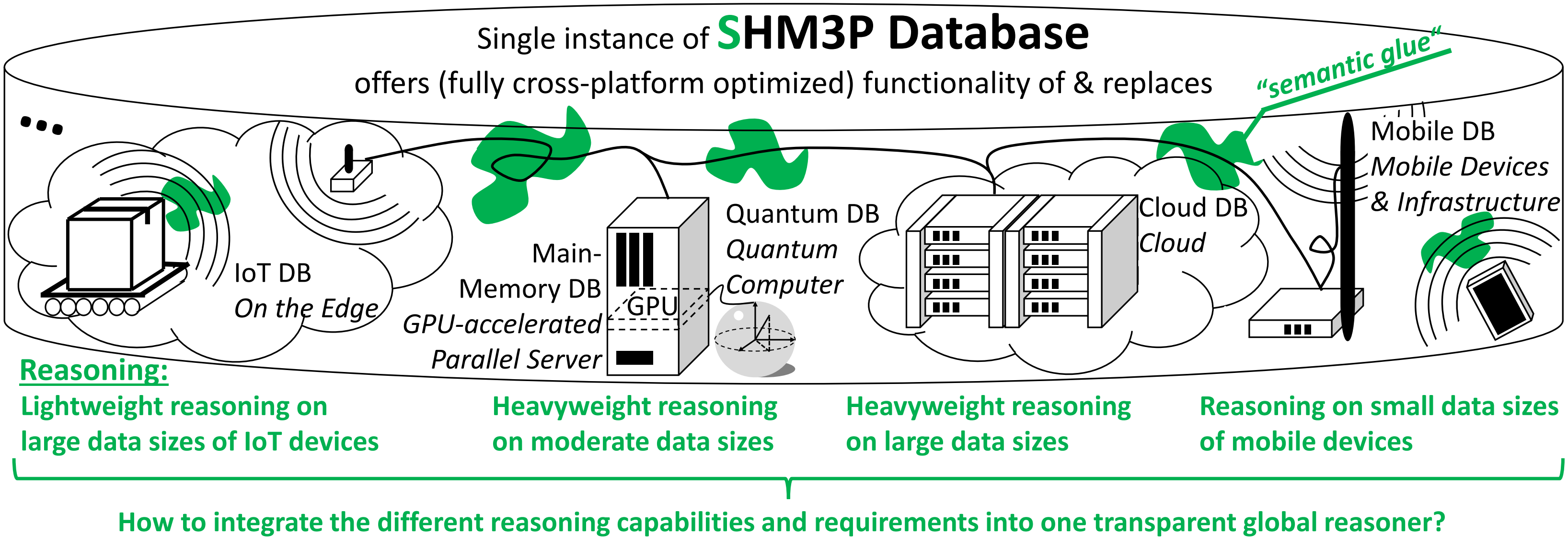
Challenges for HM3P Databases 1/2

- developing only one code base for the different platforms, but not introducing performance overhead in comparison to single platform databases
- identifying common properties of several platforms and reusing those approaches (like fault tolerance mechanisms) in different combinations, which are best suitable for these considered platforms
- data distribution among different platforms (applying different data distribution approaches as well)
- data distribution strategies considering overall the different properties of used platforms and models (like fast reads on parallel servers (using relational databases) and fast updates in cloud databases)

Challenges for HM3P Databases 2/2

- query optimization and other database tasks across different platforms, which apply different database approaches
- dealing with and integrating different privacy and security mechanisms supporting different privacy and security levels in the different platforms (with research e.g. on querying heterogeneous encrypted data)
- concurrency control approaches of different type have to be combined and work in cooperation (like 2 phase locking for server platforms and optimistic concurrency control for P2P networks)
- combining different types of databases (on different platforms) to offer the best of these databases and platforms *under one hood* to applications and users transparently or via intelligent integration into query language and API, e.g.,
  - guaranteeing atomicity and isolation in transactions for the data stored on a parallel server, but not for those data in the cloud supporting fast updates

Semantic Hybrid Multi-Model Multi-Platform (SHM3P) Database



- How to integrate the semantic layer between different types of databases and support semantic processing specialities like reasoning over the boundaries of different platforms?

Challenges for **S**HM3P Databases

- integrating different data models in a semantic layer on top of the underlying data models
- efficient transformations from and to the semantic model in an operational system
- developing efficient semantic querying and reasoning over the integrated data of different models
- global reasoning over reasoners running on different platforms supporting some kind of distributed heterogeneous reasoning
- developing a combination of stream reasoning over streaming data (e.g. of IoT devices) with static reasoning over large-scale data sets (stored e.g. in clouds)
- supporting transactions over semantic data by integrating the reasoner in transaction synchronization

Summary and Conclusions

- Internet-of-Things as extension of the Internet for advanced applications by connected things
- Routing Protocols with RPL as example
- Query Processing as example for data management tasks
- Combining routing and query processing for reducing communication costs as example for new research in IoT by combining approaches of the network and database community
- The bigger picture: Combining approaches designed for various platforms with specific properties and benefits