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Temporal Management of RFID Data

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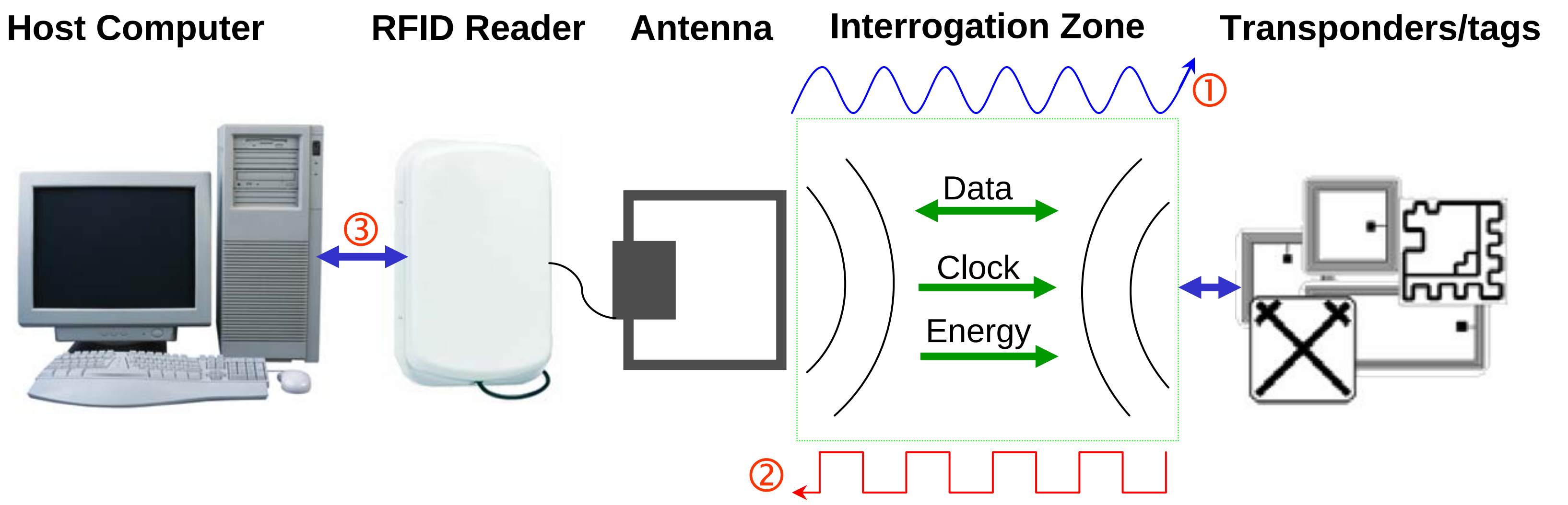
Outline

- Overview of RFID Technology
- Temporal Data Modeling of RFID Data
- Querying RFID Data
- Automatic Data Acquisition and Transformation
- Partitioning-Based Archiving
- Siemens RFID Middleware
- Related Work
- Conclusion

What is RFID

- RFID is an Automatic Identification and Data Capture (AIDC) technology that uses radio-frequency waves to transfer data between a reader and a movable object to identify, categorize, and track the object
- RFID is fast, reliable, and does not require line of sight or contact between reader/sensor and the tagged object
- Gradually adopted and deployed
  - Supply chain management/logistics: Wal-Mart, Metro Group, DOD
  - Retail: Future Store Initiative
  - Anti-counterfeiting and security: FDA, Homeland Security
  - Healthcare: Siemens's bracelet, smart medicine
  - …

How RFID Works



③Reader decodes and sends it to the host computer

②Tag sends ID/data back to the reader

①Reader sends energy to tag for power

- Reader sends energy to tag for power
- Tag sends ID/data back to the reader
- Reader decodes and sends it to the host computer

Benefits of RFID Technology

- RFID tags are identified by an unique ID around the world, defined by the EPC standard
- Through automatic data collection, RFID technology can achieve:
  - Greater visibility an product velocity across supply chains
  - More efficient inventory management
  - Easier product tracking and monitoring
  - Reduced product counterfeiting and theft
  - Much reduced labor cost
- To achieve these benefits:
  - RFID observations need to be automatically filtered, interpreted and semantically transformed into business logic, so they can be quickly integrated into business applications

Characteristics of RFID Data

- Temporal and history oriented
  - Observations generate new events, and carry state changes
  - Location and aggregation change along the time

  → Expressive data model needed
- Inaccurate data and implicit semantics
  - Noisy data and duplicate readings
  - Observations imply location changes, aggregations, and business processes

  → Automated data filtering and transformation needed
- Streaming and large volume
  - Large data are collected and preserved for tracking and monitoring

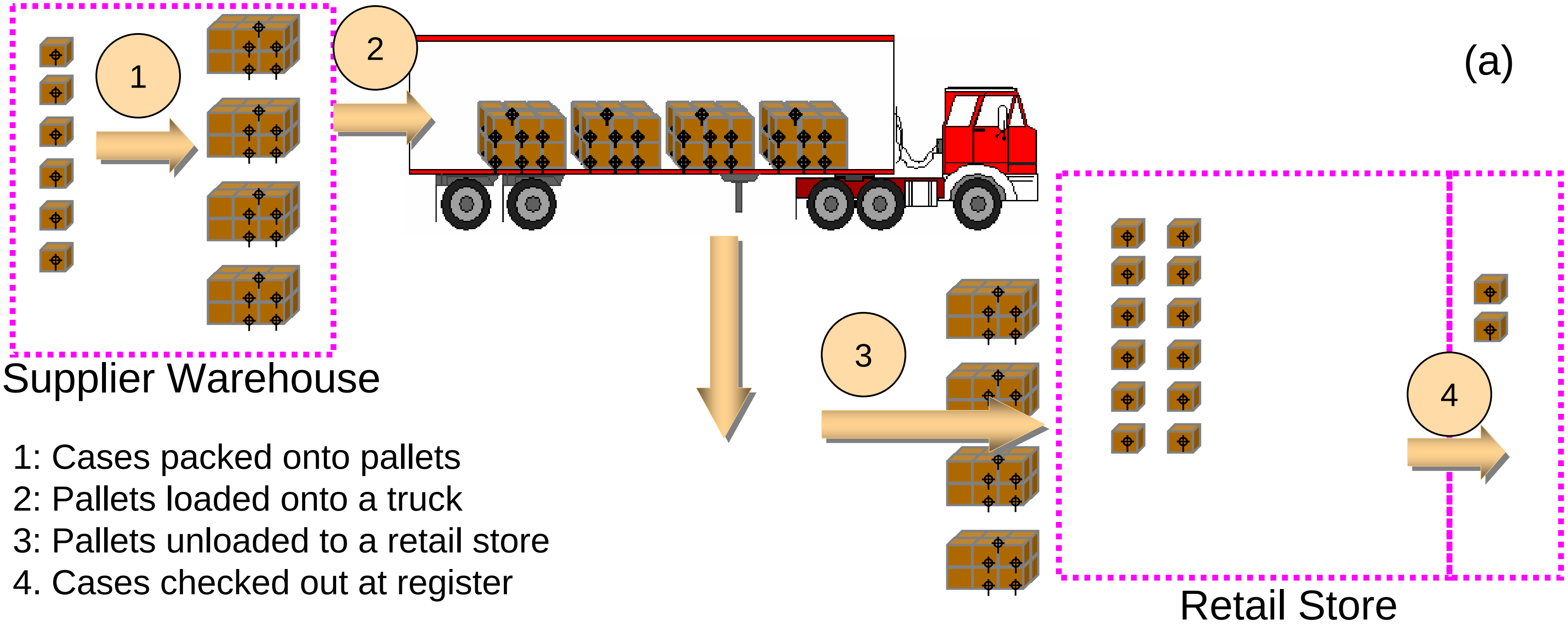
  → Scalable storage scheme needed, to assure efficient queries and updates
- Integration
  - RFID data need to be integrated into existing applications

  → Minimum effort required

Our Contributions

- An expressive temporal-based data model
- Effective complex query support for tracking and monitoring
- Partitioning-based archiving provides effective storage and assures update performance
- Rules-based framework for automatic data filtering and transformation
- Adaptable and portable RFID data management system: Siemens RFID Middleware

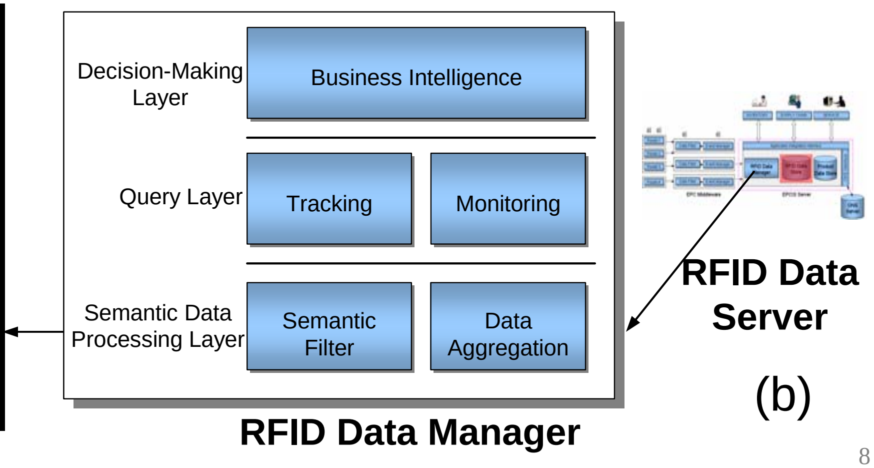
A Sample RFID-enabled Supply Chain System



1: Cases packed onto pallets
2: Pallets loaded onto a truck
3: Pallets unloaded to a retail store
4. Cases checked out at register

Reader RFID Tables	D	1	2	3	4
SENSOR	x				
OBJECT		x	x		
LOCATION	x				
TRANSACTION					x
OBSERVATION		x	x	x	x
CONTAINMENT		x	x	x	
OBJECTLOCATION		x	x	x	x
TRANSACTIONITEM					x
SENSORLOCATION	x				

D: deployment

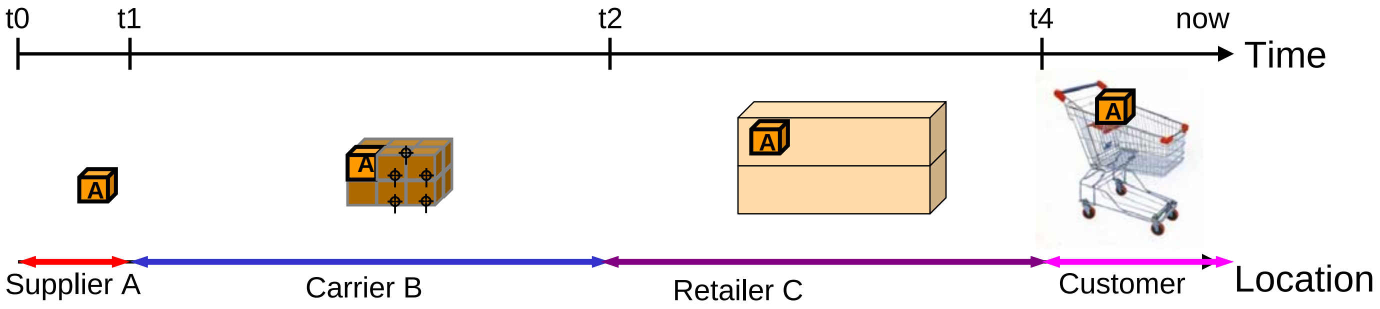


Fundamental Entities in RFID Systems

- Objects
  - EPC-tagged objects: e.g., items, cases, pallets, trucks, patients
- Sensors/readers
  - Each reader (or its antenna) is also uniquely identified by an EPC
- Locations
  - Symbolized locations to represent where an object is/was
- Transactions
  - Business transactions involving EPC tags
  - Not considered in many RFID applications

Dynamic Interactions between RFID Entities

- State changes
  - Object location change *(object + location)*
  - Object containment relationship change *(object + object)*
  - Reader location change *(reader + location)*
- New events
  - Observations *(reader + object)*
  - Transacted items *(transaction + object)*
- e.g., object location change history:



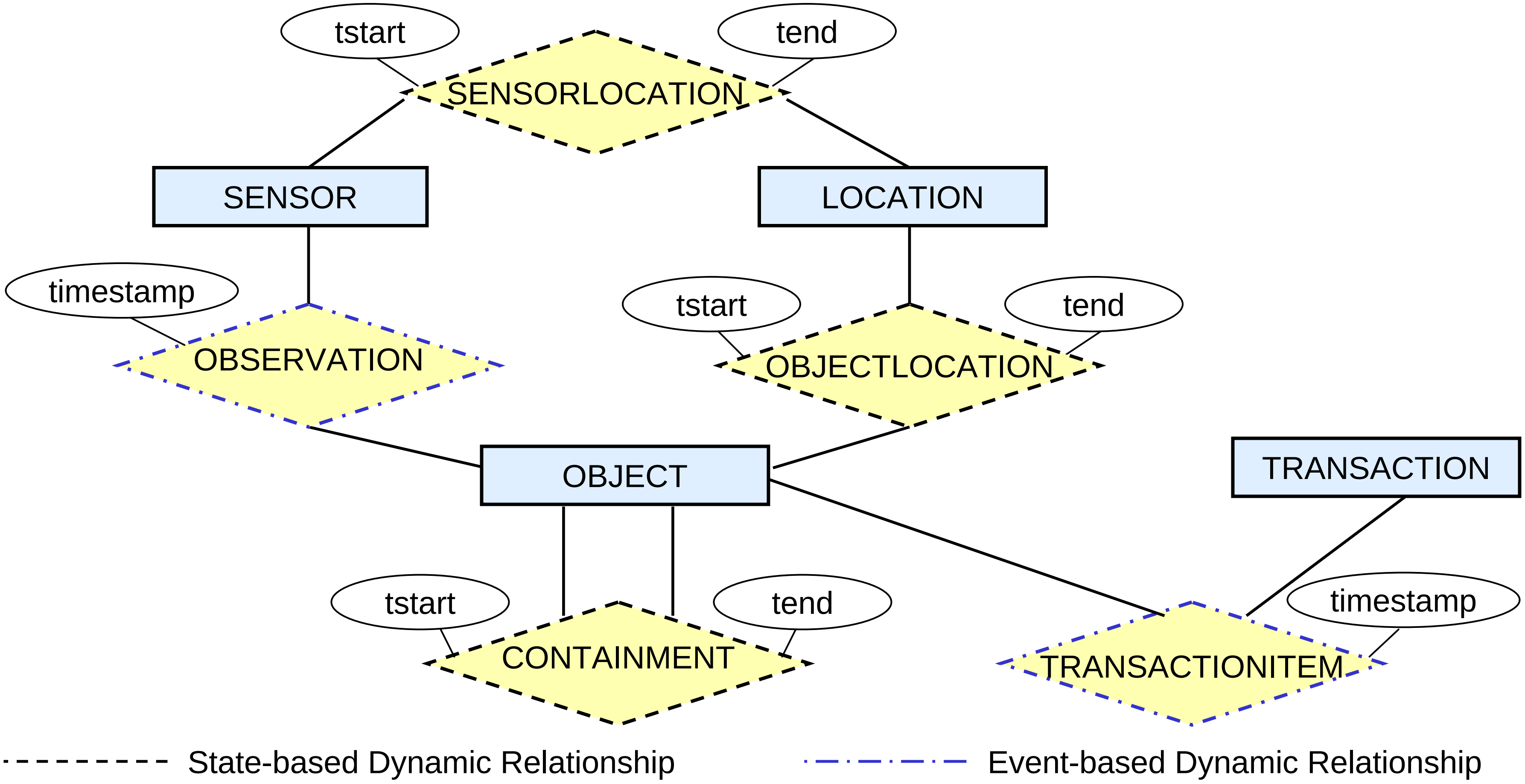
Dynamic Relationship ER Model (DRER)

- RFID entities are static and are not altered in the business processes
- RFID relationships: dynamic and change all the time
- Dynamic Relationship ER Model
  - Simple extension of ER model

  Two types of dynamic relationships added:

  - Event-based dynamic relationship. A *timestamp* attribute added to represent the occurring timestamp of the event
  - State-based dynamic relationship. *tstart* and *tend* attributes added to represent the lifespan of a state

Dynamic Relationship ER Model (DRER) (cont'd)



Dynamic Relationship ER Model (DRER) (cont'd)

- Static entity tables

OBJECT (epc, name, description) SENSOR (sensor_epc, name, description)

LOCATION (location_id, name, owner) TRANSACTION (transaction_id, transaction_type)

- Dynamic relationship tables

TRANSACTION (transaction_id, transaction_type)

OBSERVATION (sensor_epc, value, timestamp)

SENSORLOCATION (sensor_epc, location_id, position, tstart, tend)

TRANSACTIONITEM (transaction_id, epc, timestamp)

OBJECTLOCATION:

epc	location_id	tstart	tend
urn:epc:id:gid:1.1.1	L001	2004-10-30 17:33:00.000	2004-11-01 10:35:00.000
urn:epc:id:gid:1.1.1	L002	2004-11-01 10:35:00.001	2004-11-07 11:00:00.000
urn:epc:id:gid:1.1.1	L003	2004-11-07 11:00:00.001	2004-11-08 15:30:00.009
urn:epc:id:gid:1.1.1	L004	2004-11-08 15:30:00.010	9999-12-31 23:59:59.999

CONTAINMENT:

epc	parent_epc	tstart	tend
urn:epc:id:gid:1.1.1	urn:epc:id:gid:1.2.1	2004-11-01 10:33:00.100	2004-11-07 11:00:00.000
urn:epc:id:gid:1.1.2	urn:epc:id:gid:1.2.1	2004-11-01 10:33:00.110	2004-11-07 11:00:00.010
urn:epc:id:gid:1.2.1	urn:epc:id:gid:1.3.1	2004-11-01 10:35:00.001	2004-11-07 10:59:00.000

Tracking and Monitoring RFID Data

- RFID object tracking: find the location history of object “EPC”

```
SELECT * FROM  OBJECTLOCATION WHERE epc='EPC'
```

- Missing RFID object detection: find when and where object “mepc” was lost

```
SELECT location_id, tstart, tend
FROM   OBJECTLOCATION
WHERE  epc='mepc' and tstart =(
             SELECT MAX(o.tstart)
             FROM  OBJECTLOCATION o
             WHERE o.epc=‘mepc')
```

- RFID object identification: a customer returns a product “XEPC”. Check if the product was sold from this store

```
SELECT * FROM  OBJECTLOCATION
WHERE epc='XEPC' AND location_id='L003'
```

Tracking and Monitoring RFID Data (cont’d)

- RFID object snapshot query: find the direct container of object “EPC” at time T

```
SELECT parent_epc FROM   CONTAINMENT
WHERE  epc='EPC' AND  tstart <= 'T' AND tend >= 'T'
```

- RFID object temporal slicing query: find items sold to customers in the last hour

```
SELECT epc FROM OBJECTLOCATION
WHERE location_id = 'L04' AND tend = 'UC'
               AND tstart <= sysdate-(1/24)
```

- RFID object temporal join query: this case of meat is tainted. What other cases have ever been put in the same pallet with it?

```
SELECT c2.epc FROM CONTAINMENT c1, CONTAINMENT c2
WHERE c1.parent_epc = c2.parent_epc
  AND c1.epc = 'TEPC'
  AND overlaps(c1.tstart,c1.tend,c2.tstart,c2.tend)
```

Tracking and Monitoring RFID Data (cont'd)

- Temporal aggregation of RFID data: find how many items loaded into the store “L003” on the day of 11/09/2004

```
SELECT count(epc)FROM OBJECTLOCATION
WHERE location_id = 'L003'
   AND tstart <= '2004-11-09 00:00:00.000'
   AND tend  >= '2004-11-09 00:00:00.000'
```

- RFID object containment query: sibling search: find all objects contained in object “PEPC”

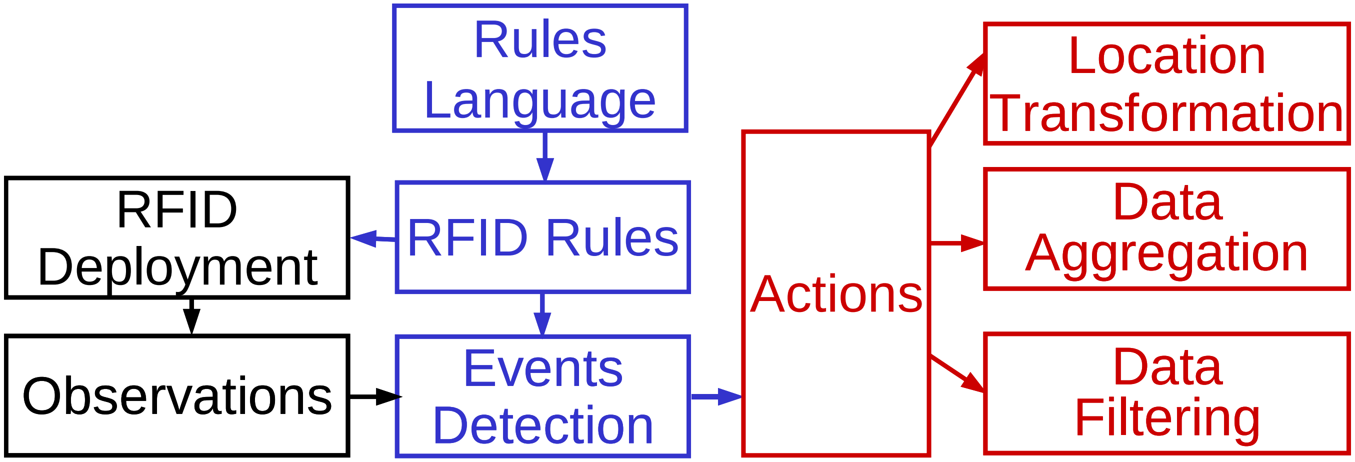
```
WITH RECURSIVE all_sub(parentepc, epc)  AS
( SELECT parentepc, epc  FROM CONTAINMENT
  WHERE parentepc = 'PEPC'
  UNION
  SELECT a.parentepc, c.epc
  FROM all_sub a, CONTAINMENT c
  WHERE a.epc = c.parentepc
)
SELECT *
```

RFID Data Transformation

- RFID data acquisition
  - Two modes: inventory mode for multiple tag detection at once, and sequential mode
  - Data are susceptible to interference (especially from water and metal)
- Acquired data need to be automatically transformed into high level semantic data, through:
  - **RFID data filtering:** data smoothing to remove noise, and duplicate detection to remove duplicates
  - **Location transformation:** observations transformed into location changes
  - **Data aggregation:** observations transformed into semantic relationship among RFID objects, such as containment

Rules-based RFID Data Transformation

- Location changes are triggered by primitive readings from certain readers
- Data aggregation is through sequence of operations following certain patterns
- Rules detect the patterns through event detection, and lead to modifications in the database
- Rules defined through a declarative event and constraint specification language



Rules for Data Transformation and Aggregation

- Rules for data filtering

```
OBSERVATION(Rx, e, Tx), OBSERVATION(Ry, e, Ty),
Rx <> Ry, within(Tx, Ty, T) ->
  DROP:OBSERVATION(Rx, e, Tx)
```

- Rules for location transformation

```
OBSERVATION("R2", e, t) ->
  UPDATE:OBJECTLOCATION(e,"L002", t, "UC")
```

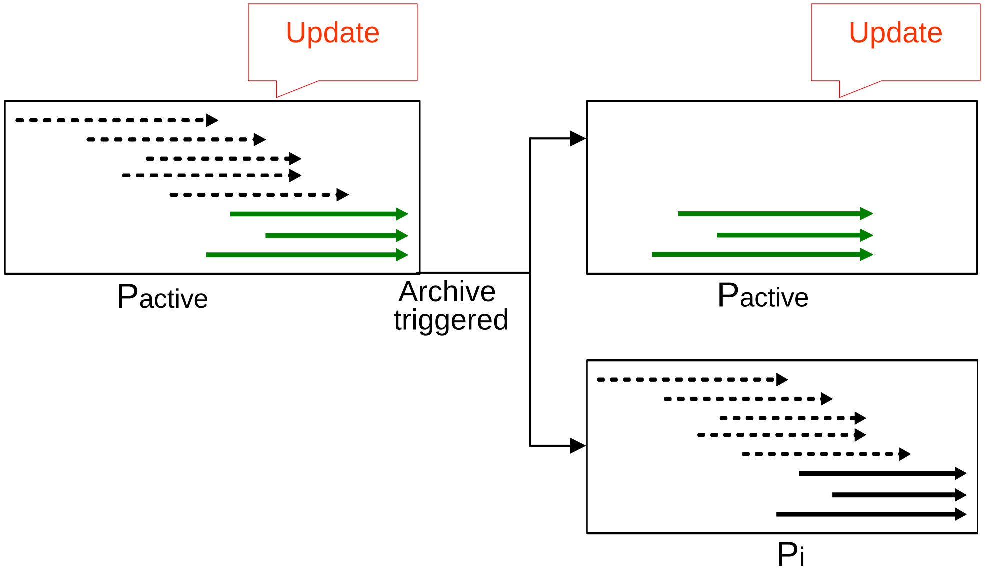
- Rules for data aggregation

```
 seq(s,"r2“,Tseq);OBSERVATION("r2", e, t) ->
  INSERT:CONTAINMENT(seq(s,"r2“,Tseq),e,t,"UC")
```

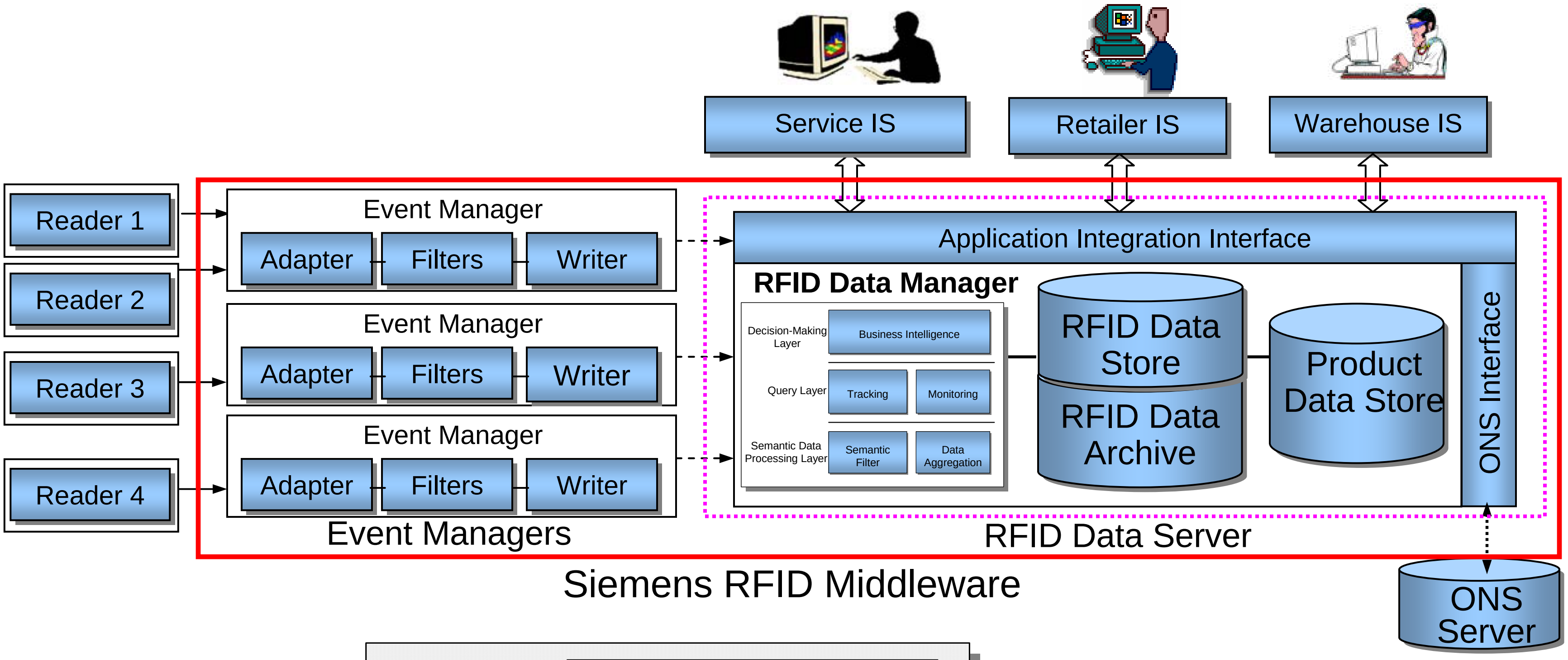
- Data generation from rules actions
  - States and events modifications in the databases (link)
  - In particular, when a parent container is updated with a location change, the locations of all its contained objects will be updated

Data Partitioning

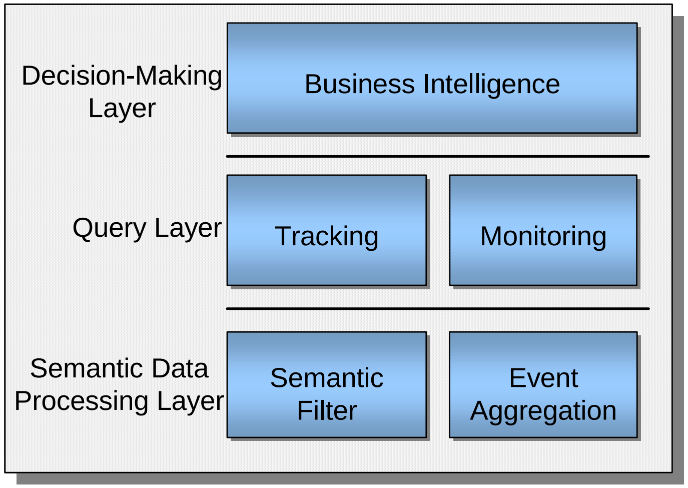
- Increase of data volumes slows down queries
- Data have a limited active cycle
  - Non-active objects can be periodically archived into history segments
  - Active segments with a high active object ratio is used for updates
- This partition technique assures efficient update and queries



Siemens RFID Middleware



Siemens RFID Middleware



RFID Data Manager

Middleware Components

- Event Managers – a set of event managers
  - Adapter: software component to communicate readers
  - Filter: preliminarily filter raw reading data
  - Writer: route data to different targets
- RFID Data Server
  - RFID Data Manager: filtering, aggregation, modeling, queries and decision support
  - RFID Data Store: schemas and storage of RFID data
  - RFID Data Archive: history archive of RFID data
  - Application integration interface: integrate with business applications
  - ONS integration interface: exchange of product-level information

Future Work

- Data management for all types of RFID data
  - Support different EPC classes and reader/location scenarios

Reader/Location/Operation	Tag Type	Class 0,1 Read-only	Class 2 Reader-write	Class 3 Sensor-write (Semi-Passive)
Fixed Reader	Fixed Location	A	F	G
Moveable Reader	No Location	B	-	-
	Discrete Location	C	-	-
	Continuous Location	D	-	-
With Operation		E	-	-

- Support rules with data stream management systems
  - While standalone rule engine can process RFID data, data stream management systems provide many benefits for complex event processing
- Data analysis of RFID data
  - RFID data have unique IDs and are ordered, thus additional information can be mined

Related Work

- RFID Platforms
  - Sun EPC Network
  - SAP Auto-ID Infrastructure
  - Oracle Sensor Edge Server
  - IBM WebSphere RFID Premises Server
  - UCLA's WinRFID Middleware
  - Microsoft RFID Middleware
- These platforms serve as the bridges between the RFID physical world and the rest of the software infrastructure, but the high level RFID data modeling is up to applications

Conclusion

- We propose a general and expressive temporal-oriented data model for RFID data
- The data model is shown to be quite powerful on supporting RFID data tracking and monitoring
- The rules-based framework enables automatic RFID data filtering, transformation, and aggregation, to generate semantic high level data
- The Siemens RFID Middleware brings all these technologies together into an integrated RFID data management system
- The system is general and can be adapted into different RFID applications, thus substantially reduces the cost of managing and integrating RFID data into business applications

Questions & Answers