

Event-based Systems

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Administrivia

- Lecture: Monday 13:30 – 3CP
- Project: 3CP pass/fail, 1 overall grade for 6CP course
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- Information on DVS Web Page (News)
- Course materials: go to teaching and look for event based systems
- This is a new course with high research content, materials will be posted as they become available
- Literature recommendations will be given for each topic



The Real-Time Enterprise

From the Gartner Web Site:

- **The Real-time Enterprise is Event-driven**

Enterprises that want to operate in real time must expand their use of event-oriented design, message-oriented middleware and publish-and-subscribe communication.

- **Content Management and Portals power the RTE**

The real-time enterprise can best be realized with content management and portal adoption. The creation and sharing of unstructured information is a fundamental underpinning of the RTE.

- **Real-time Enterprises need Mobile-Enabled Middleware**

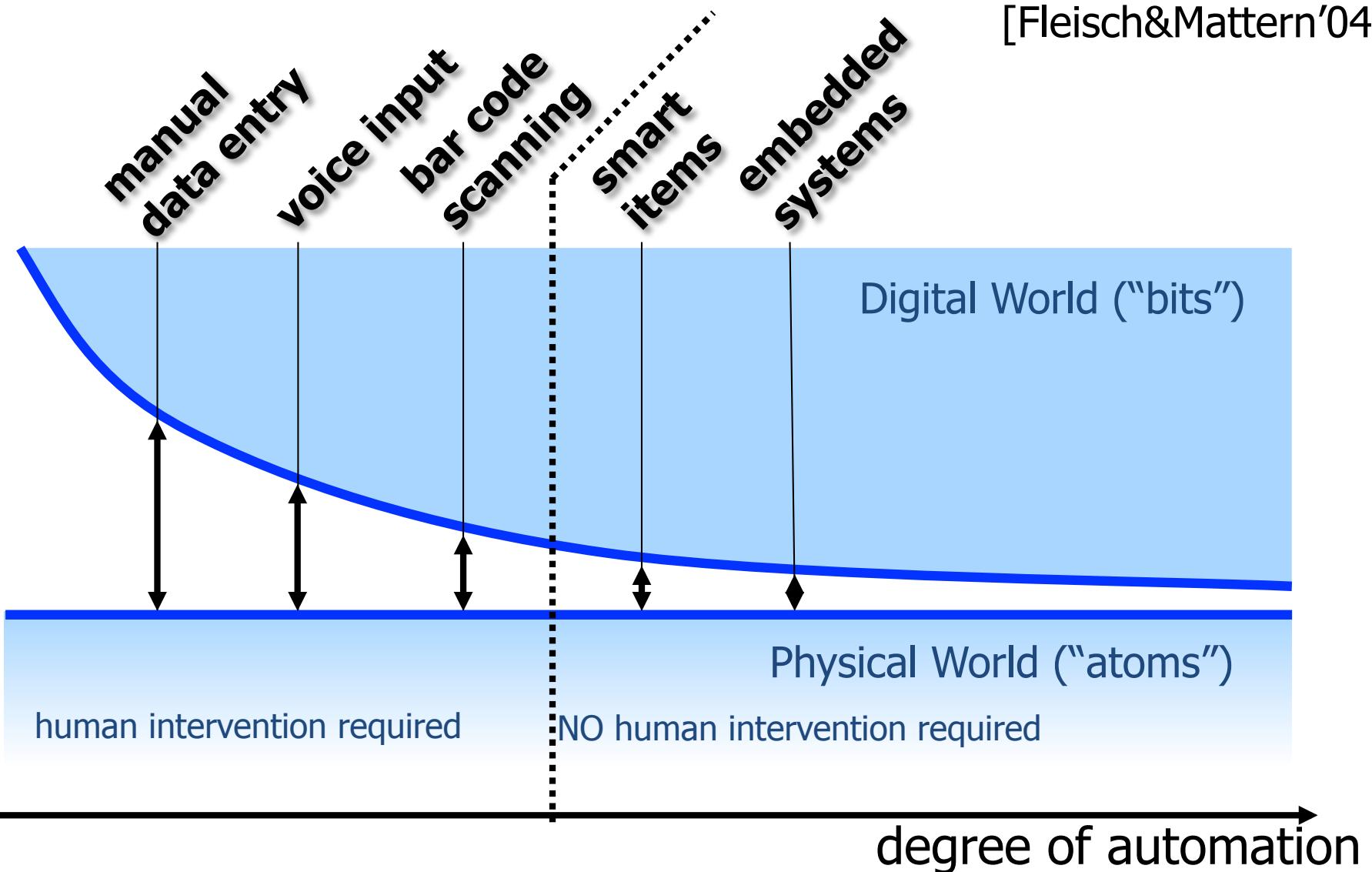
Mobile devices and wireless networks can enable the real-time enterprise. However, a sound, mobile-enabled middleware infrastructure is necessary to achieve strategic business benefits.

<http://www.gartner.com/pages/story.php?id.2632.s.8.jsp>



Merging of Physical and Digital Worlds

[Fleisch&Mattern'04]



Smart Environments Produce Streams of Events



- RFID tag detection
- Sensor readings
- Images from surveillance cameras
- Bio-data from wearable sensors
- Vehicle count/identification
- Position/context data
- Radar/Lidar, IR, imaging in autonomous vehicles
- Stock ticker
- Blog postings
- Cyberphysical systems



Stream Processing requires New Approach



Streaming data

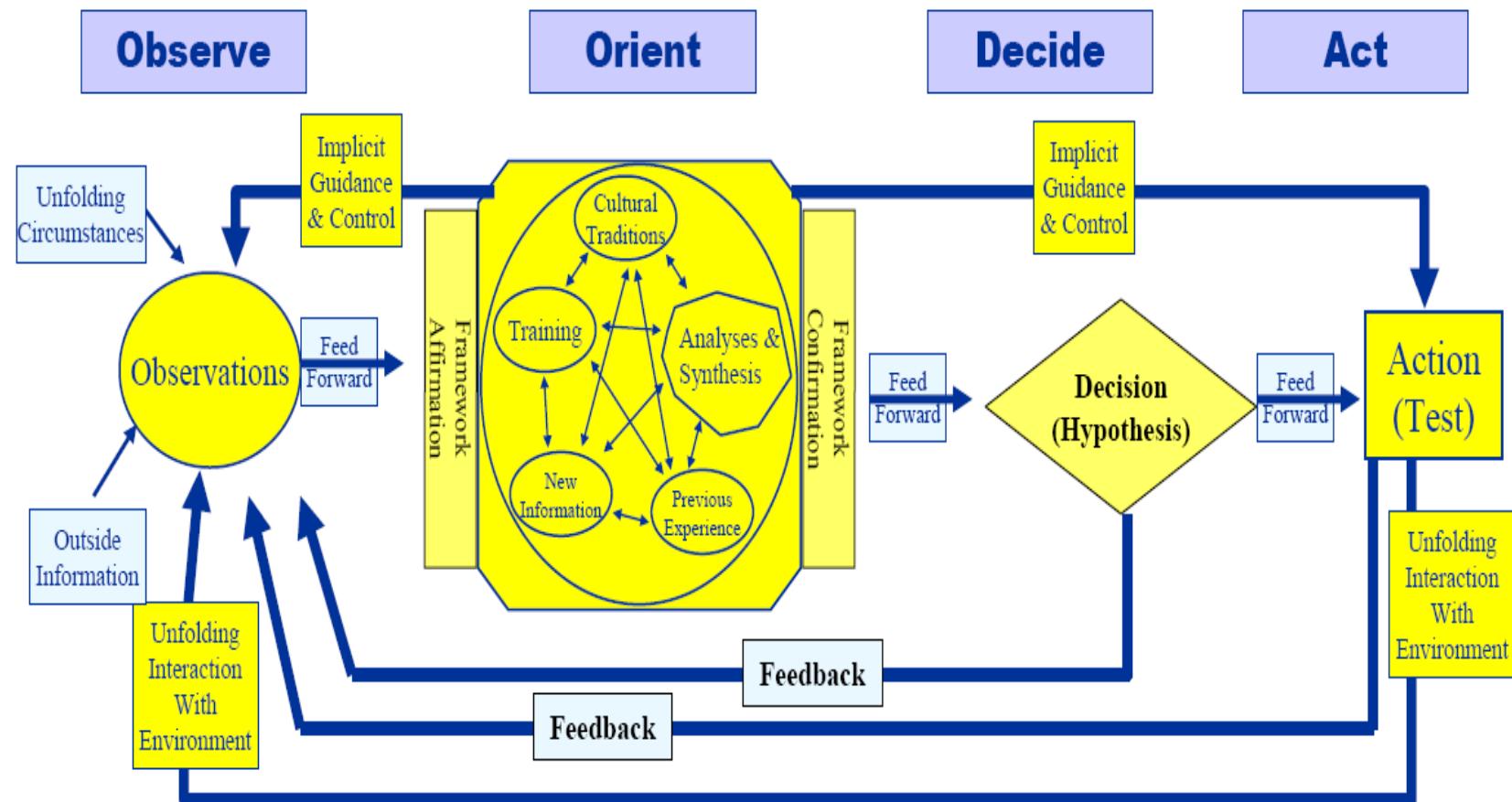
- Flowing
- *Push* = Filter & Aggregate
- Harder to control

Data in database

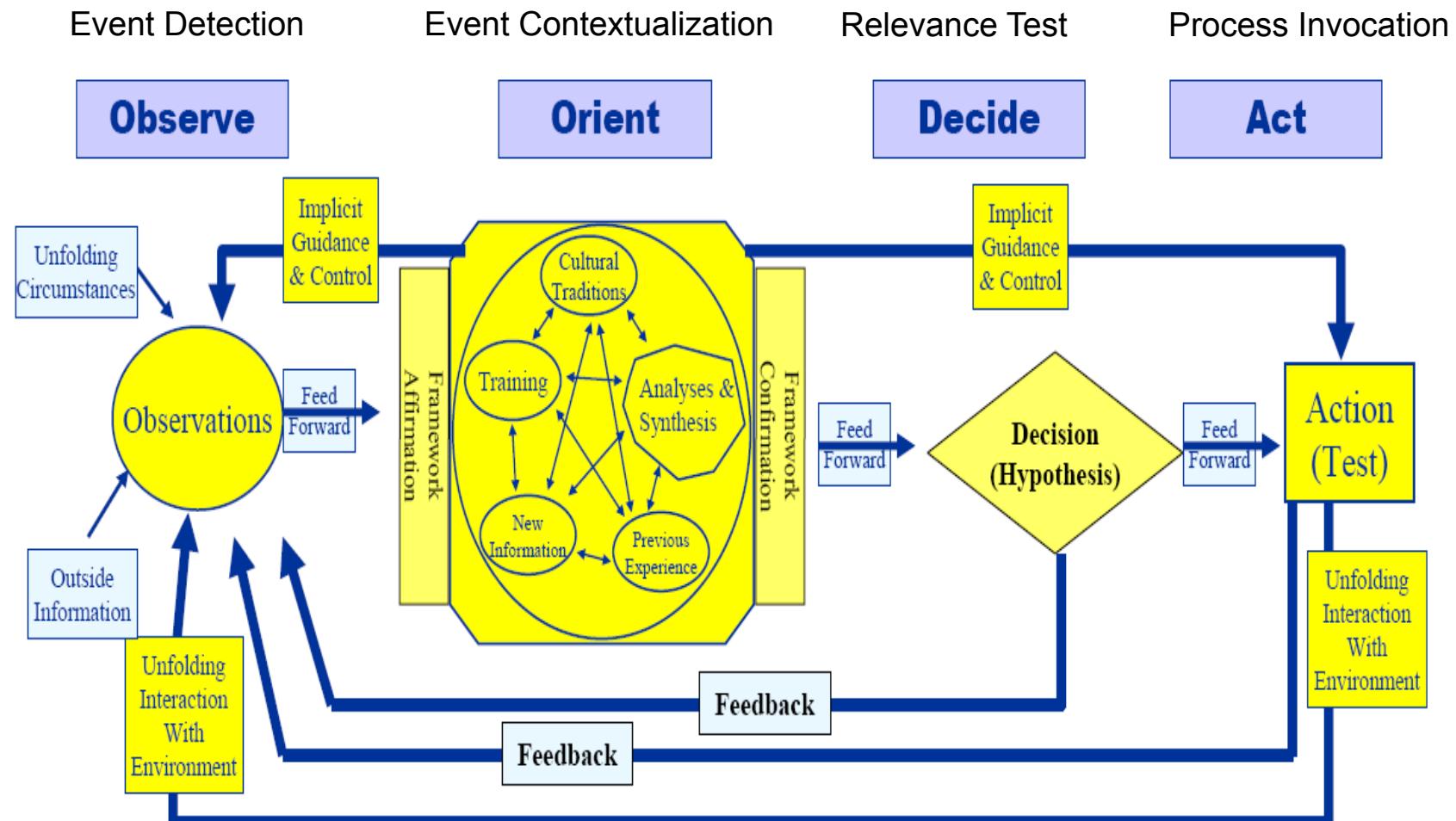
- Stationary
- *Pull* = Query
- Easy to control



The OODA Cycle (John “40 second” Boyd)



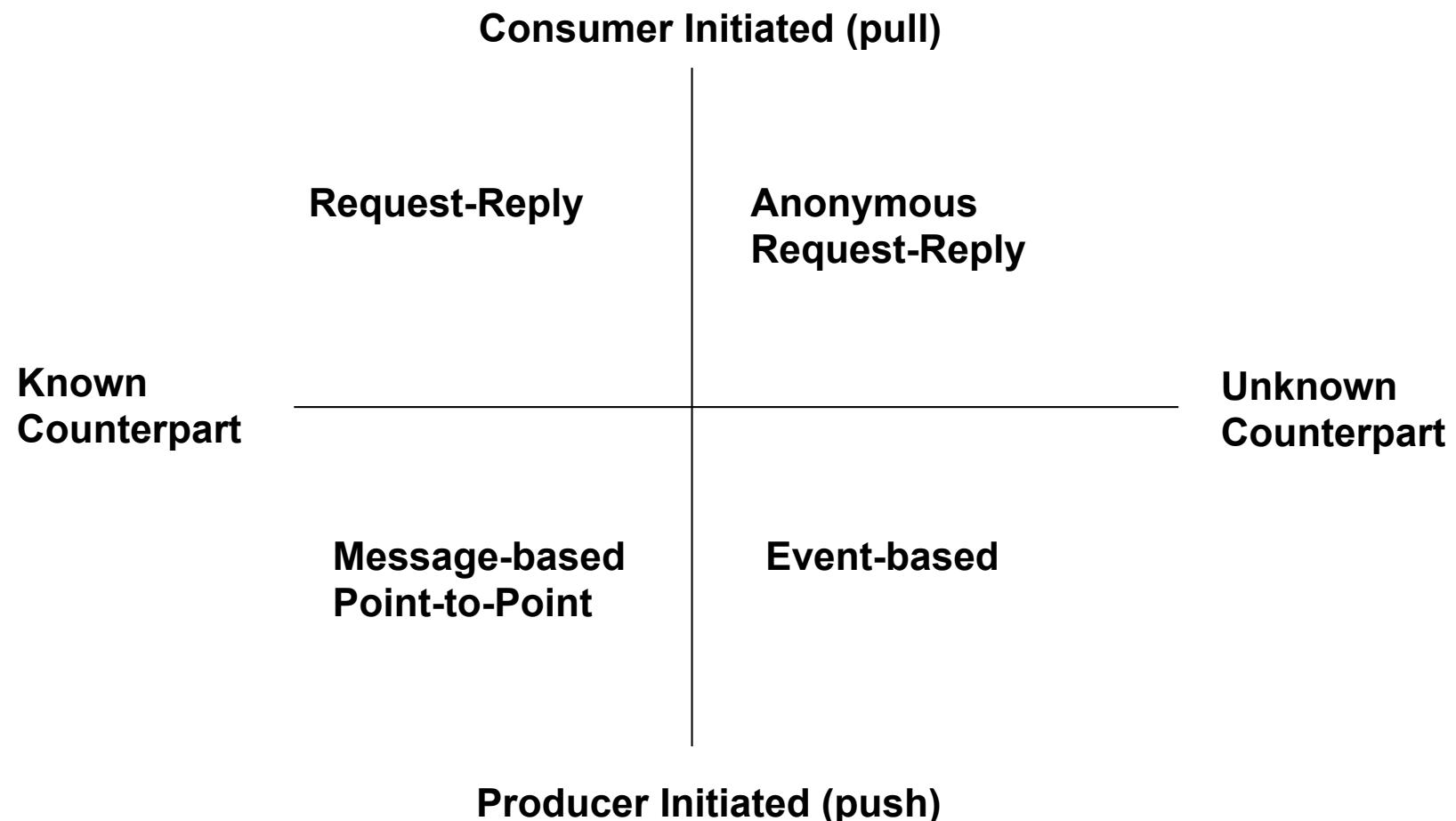
The OODA Cycle (John “40 second” Boyd)



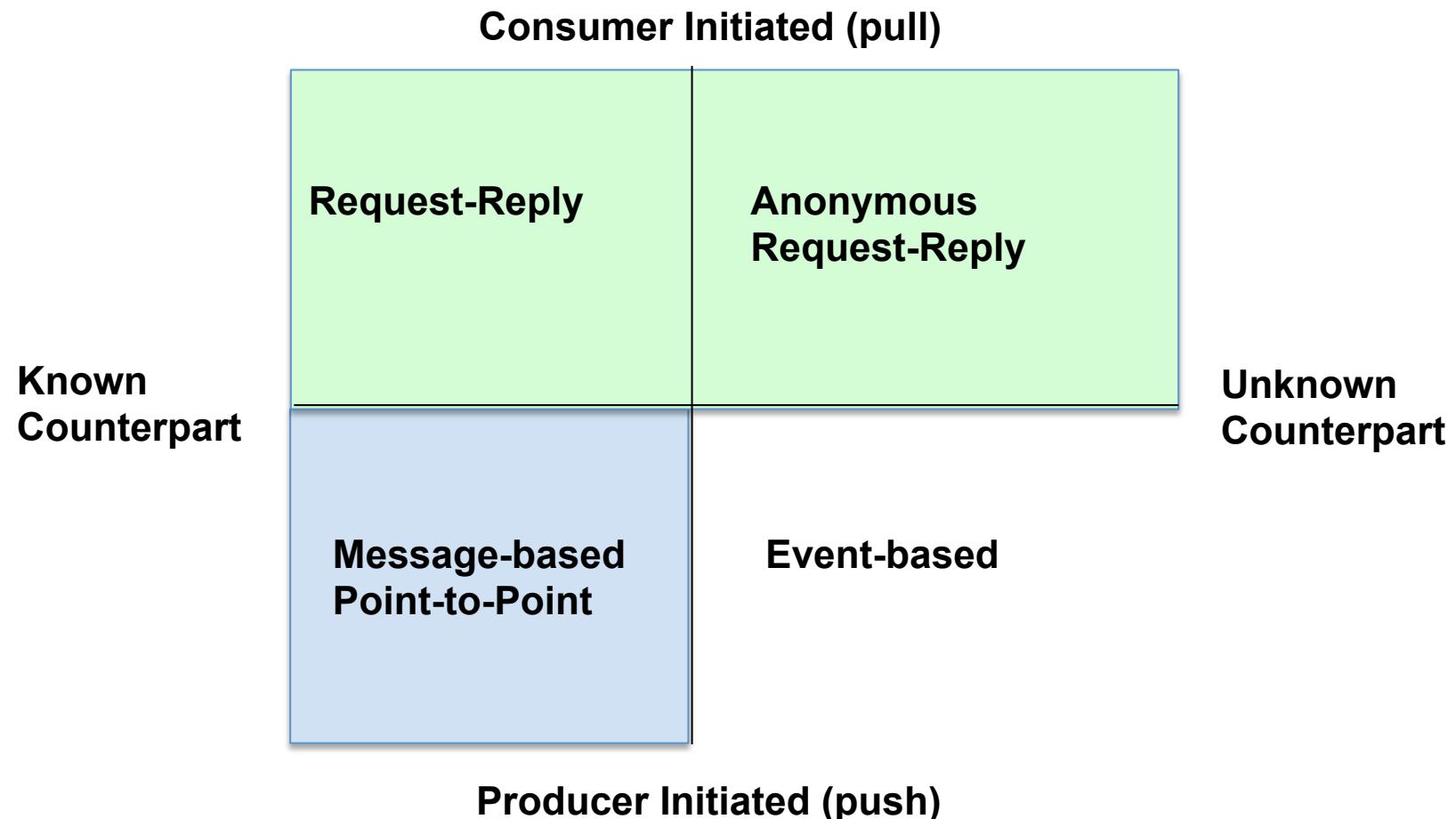
- Observation deals mostly with detection of simple events
 - From sensor signals to discrete events (event objects)
- Orientation deals with complex events
 - Event aggregation
 - Event composition
 - Event derivation
 - Contextualization of events → all together CEP
- Decision entails the comparison with (mental) model and the decision to act if deviations exceed thresholds
- Act is the reactive component that itself may impact the surroundings causing new events



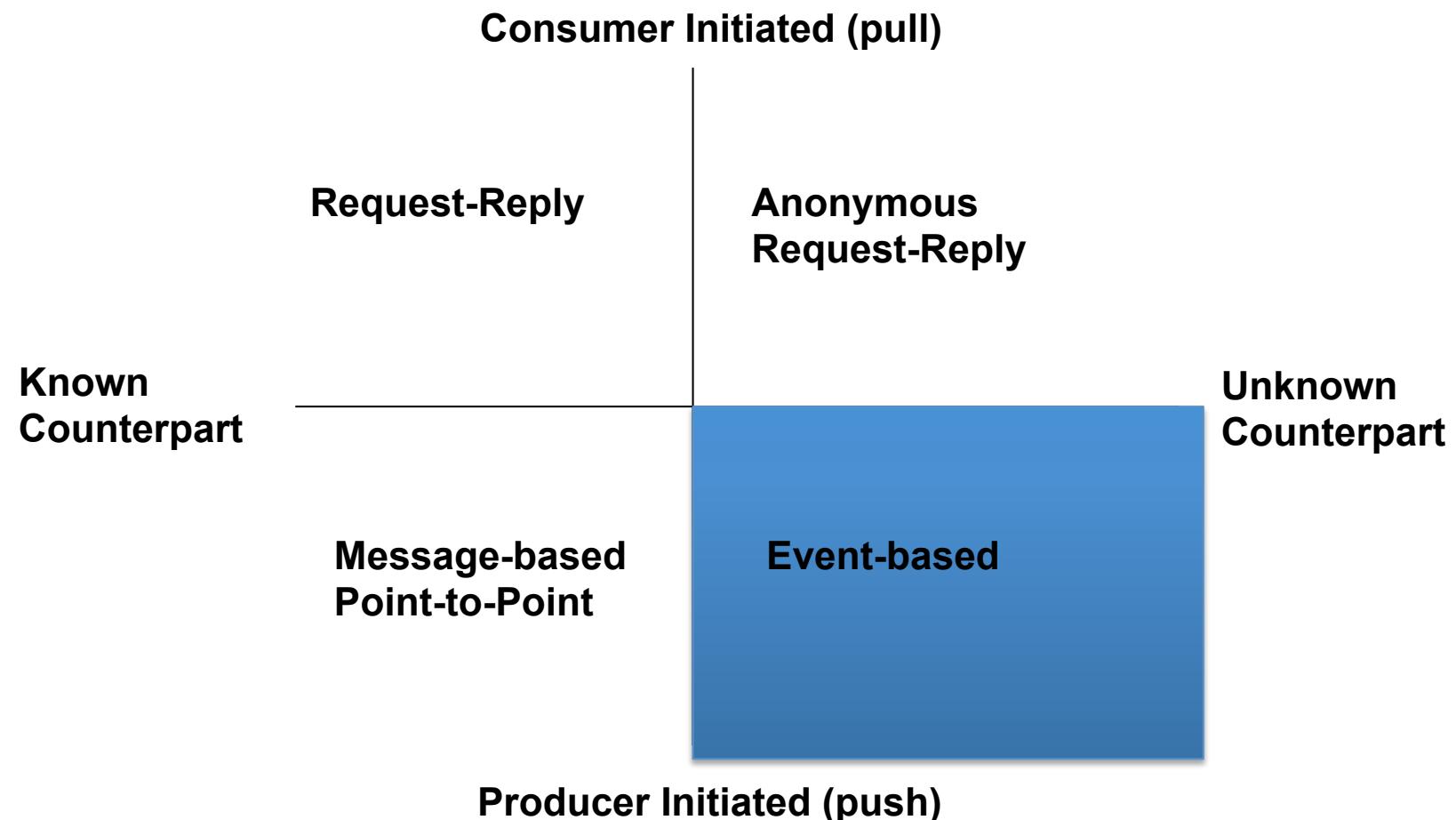
Invocation



Invocation



Invocation



Event-based Processing

- The key to event-based processing is the invocation
 - Producer of events does not know who will consume them
 - Consumer of events can't give imperative commands to producer
 - Middleware isolates producers and consumers in space and time
 - Neither producer nor consumer are blocked
 - New consumers (applications) can be added without touching the event producers
 - No application-level polling



Event Driven Architecture (EDA)

- Goals:

- Provide agility
- Provide flexibility
- Support celerity



Properties of EDA – Timeliness/Celerity

- Reporting of current events as they happen
 - No store and forward
- Pushing notifications of events from the producer to the consumer
 - Events are packaged as notifications and delivered to consumer
- Responding immediately to recognized events
 - Deferred responses are immediate responses to a complex event involving some other event (temporal or any other demarcation event)



Properties of an EDA – agility and flexibility

- Communication is one-way without need for acknowledgements
 - Event-based interaction pattern does not require an answer, i.e. the event producer will not block



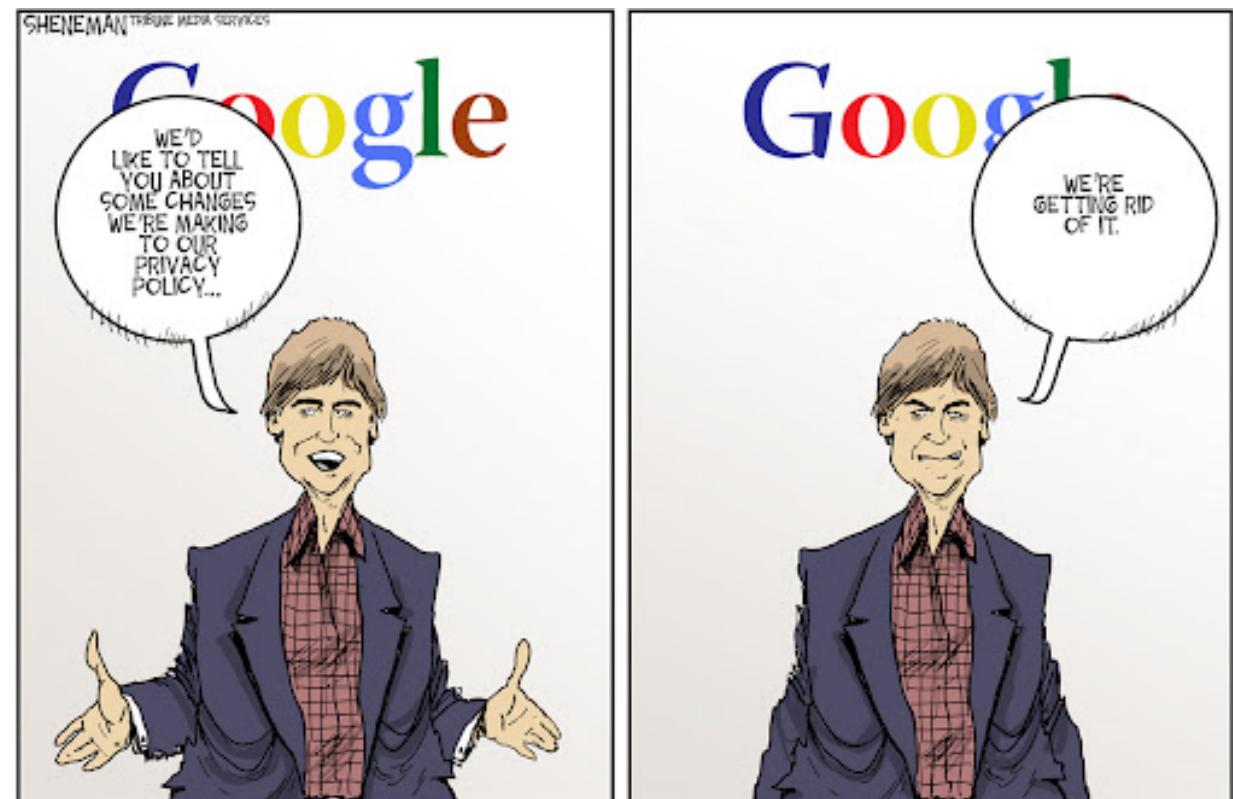
- Reaction to event notifications (no commands)
 - Interested parties must subscribe to events
 - Subscribers may unsubscribe without affecting the producers, just the notification process
 - New consumers (i.e. apps) can be added without affecting the rest of the system (except the notification mechanism)



Control in EDA

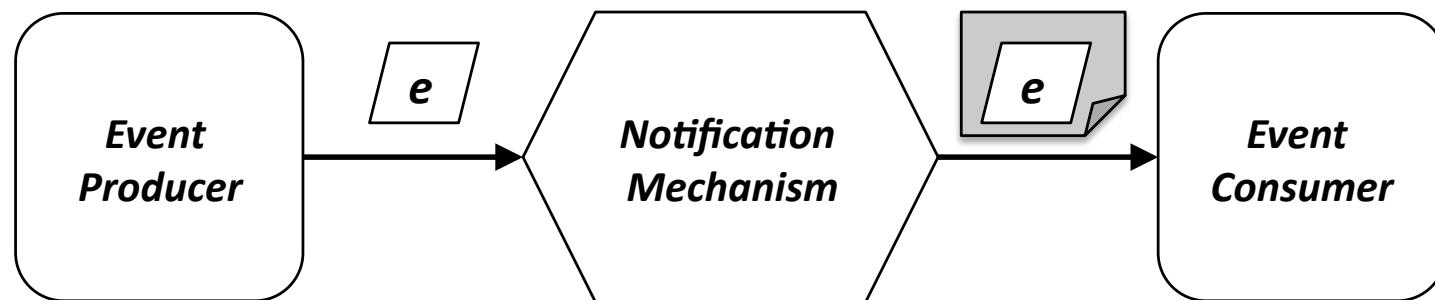
Because the event producer is not aware of the consumers, it cannot ask them to execute any actions

Event-based systems are consumer controlled

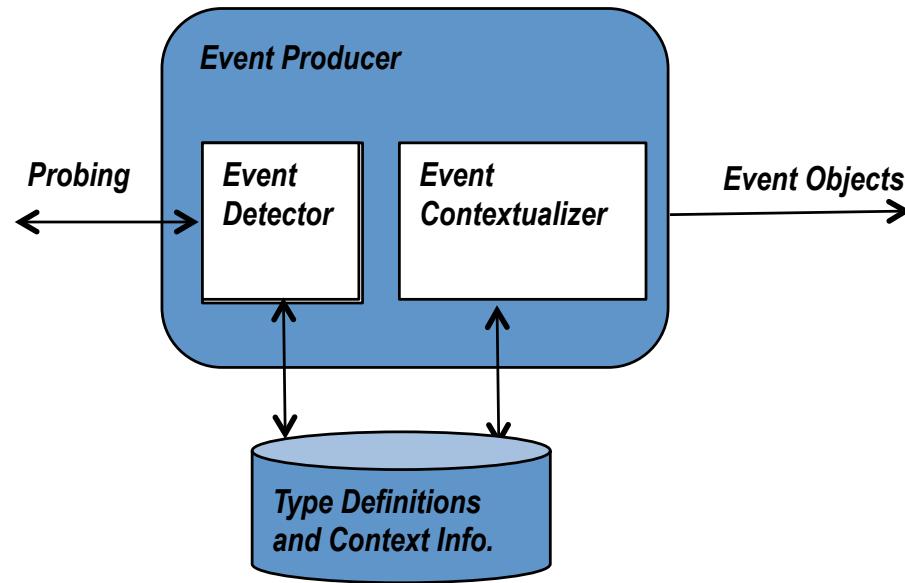


Components of an Event Driven Architecture

- Minimally, an EDA consists of event producers, event consumers and a notification mechanism



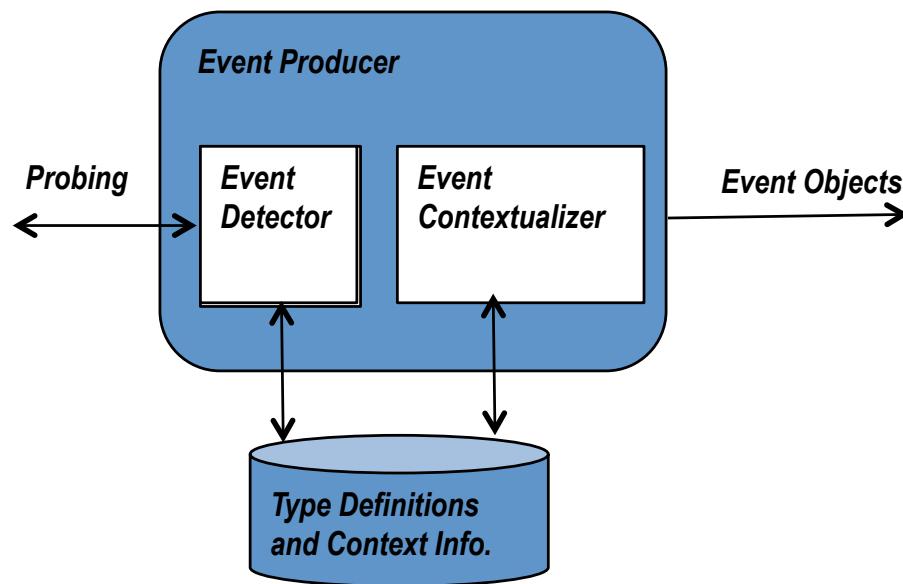
Event Producers



- Detect events and produce event objects.
- The event detection process typically will probe the environment.
- Structure of event objects is defined by event type and contains the necessary event parameters.



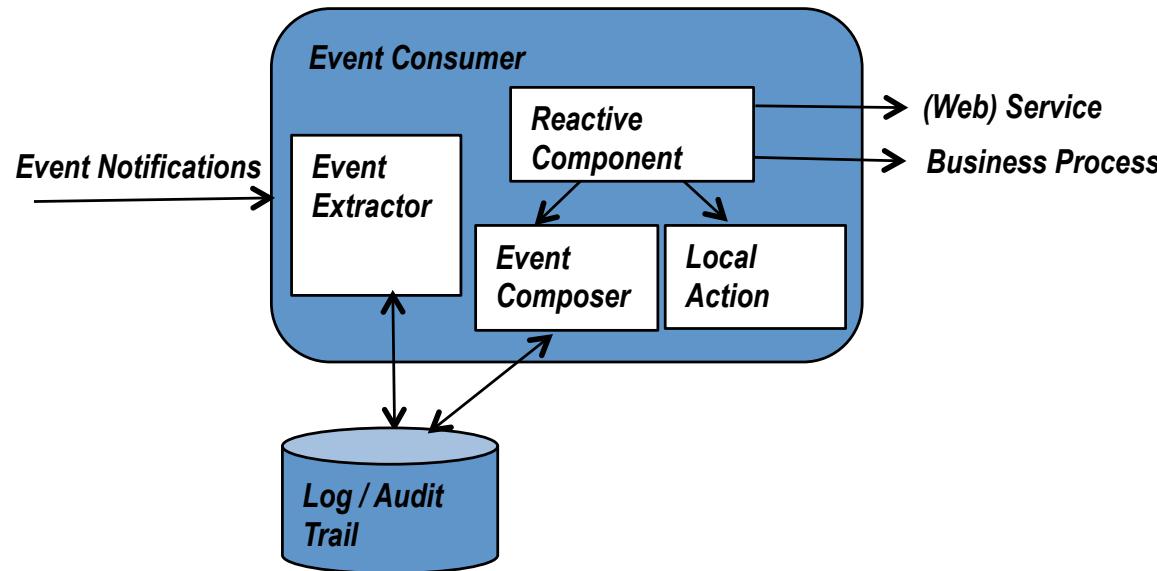
Event Producers (cont.)



- Event parameters are instantiated by the event detection process and the event contextualization process.
- The event contextualization process may rely on external data sources, type and context information may be held locally



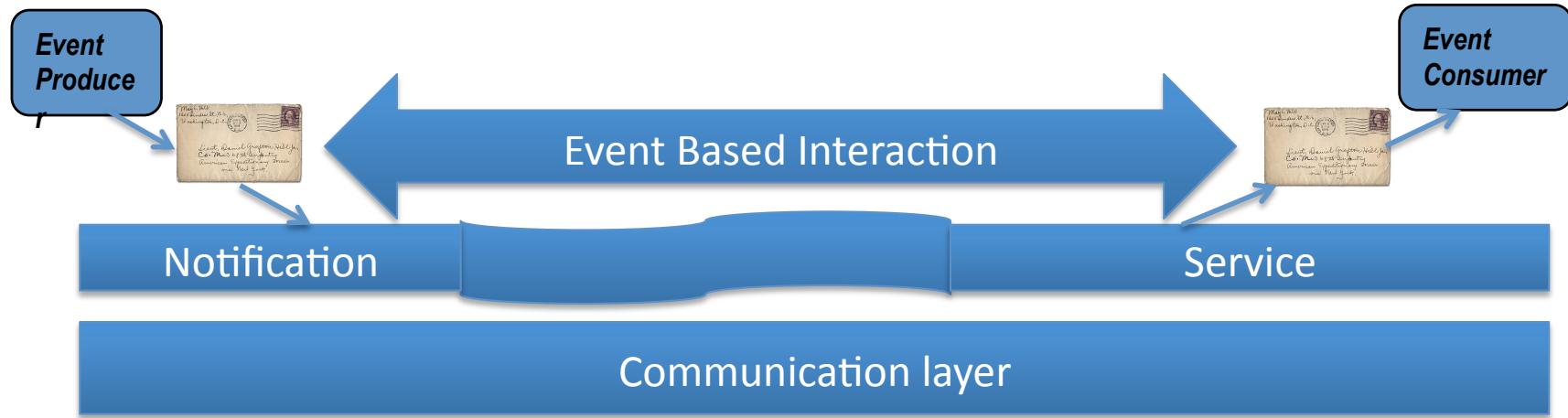
Event Consumers



- Receive event notifications from notification mechanism/service.
- Must unpack event notification, extract event object and execute an action in response to the received event.
- Response may be: local action, invocation of a (remote) service or BP, an event composition or storage of the event for logging.



Event Notification Service



- Key questions:
- How are producers and consumers brought together?
- Does the channel deliver all messages or does it filter?
- If filtering is done, on what criteria and where are the filters placed?
- Are events only routed by notification mechanism or transformed?
- If transformations are applied, where and how are they applied?



Supporting technologies:

- Active databases, materialized views, continuous queries
- Stream processing
- Data mining
- OO Middleware
- Message Oriented Middleware (MOM)
- Publish/Subscribe systems
- Reactive middleware
- Tagging systems (barcodes, RFID)
- Wireless Sensor Networks
- Sensor fusion
- Complex Event Processing (CEP)

Distributed event processing integrates these technologies for
on-the-fly event processing

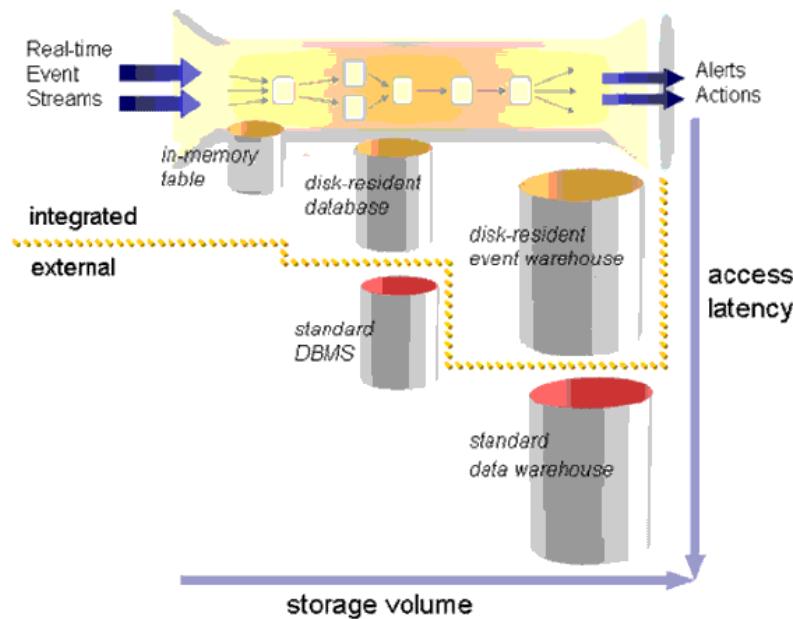


Selected DEBS Applications

- Automated trading
- Fraud detection (financial, mobile telephony, shrinkage detection)
- Baggage/package transportation and tracking
- Logistics (WSN in container, spanning containers)
- DB Cargo
- Traffic control and management
- Piping information to the cockpit
- Blog alerting and information dashboards
- Environmental monitoring
- Integrated health monitoring from home to hospital
- Ambient assisted living, smart homes
- Infrastructures for smart cities
- Threat monitoring (dirty bomb, chemical spill)
- Massively parallel multiplayer online games (MMOGs)



Stream Processing: Automated Trading



- Extremely high volume
- Streaming queries
- StreamSQL, CQL, ...
- Filtering
- Aggregation, self-joins
- Various window definitions
- Order important, must cope with out-of-order events
- Dedicated event delivery from ticker service
- Process first, store last



Fraud Detection

- Common form is superimposition fraud
- Illegal use of mobile phone, credit card, etc.
 - *Offline*: avoid aggravating customer
 - *Online*: detect and intervene
- Huge volume of call records
- Window joins, self-joins
- More sophisticated forms of fraud, e.g. insider trading (event enrichment)
- Supervision of laws and regulations, e.g. Sarbanes-Oxley, real-time risk analysis

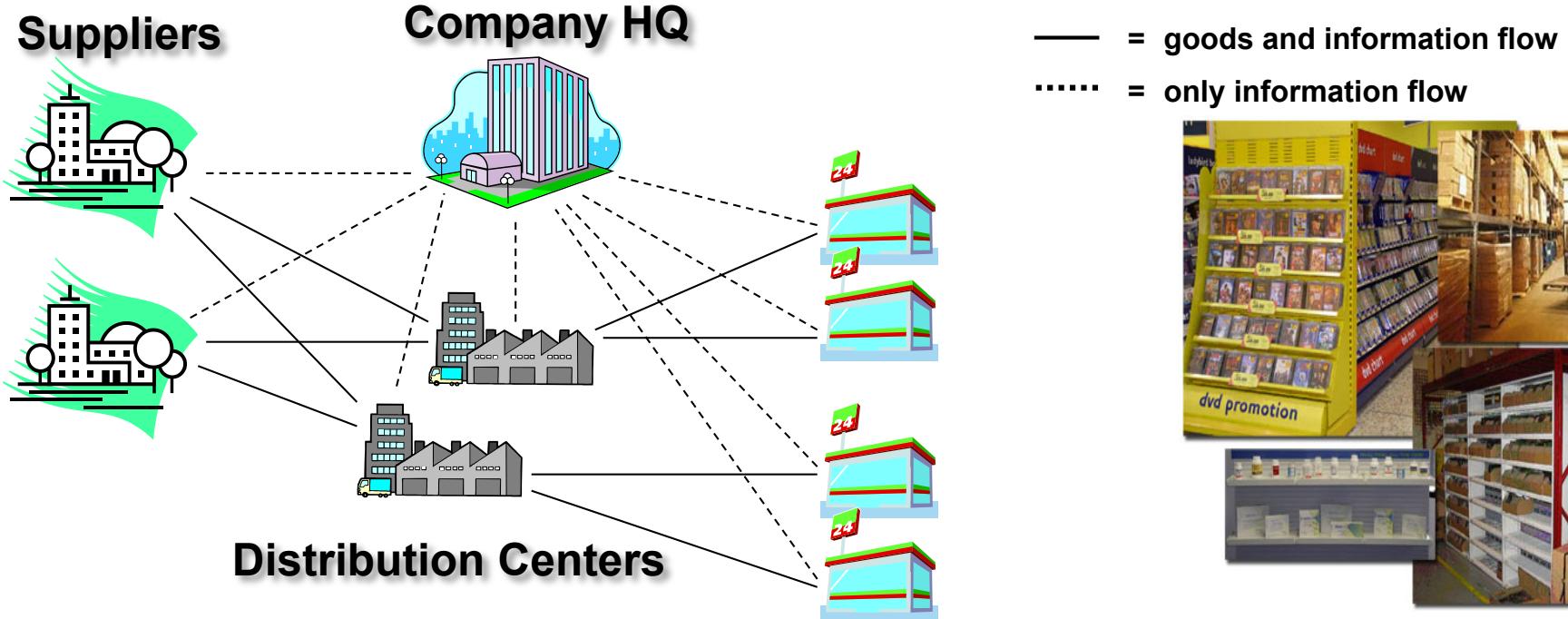


Content Creation / Content Identification

- Indexed Web contains O (100 BB) pages
- Must distinguish
 - Content creation (blogs, news, services, static sites)
 - Content identification (Digg, Technorati, Slashdot, Yahoo! Buzz, some blogs like Tech Crunch, Engadget, Gizmodo...)
- Groundbreaking work by Michael Olson (CalTech)
 - Extraction of events from blog posts, processing of these event streams
- Olson uses existing services, such as Spin3r and Calais for blog post extraction and enrichment
- Event processing is done in the Avaya EP engine
- Timely detection of relevant information on the Web is critical BI function for the RTE



RFID-based Supply-chain management



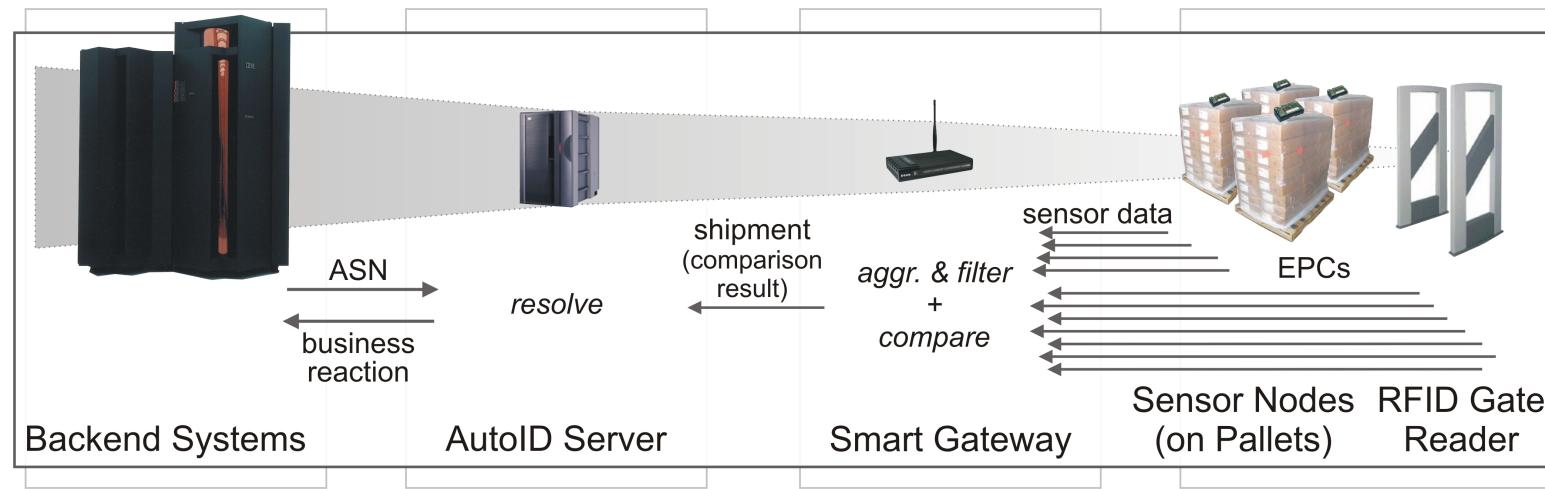
- Data captured from source to destination
- Manufacturer, warehouse, smart shelf, consumer
- Business transactions triggered by each event quite heavy
 - Multiple database accesses, bottlenecks
 - Move business rule processing to the periphery
 - Performance of notification service is critical



SAP All Rule Engine at the Edge

Goal:

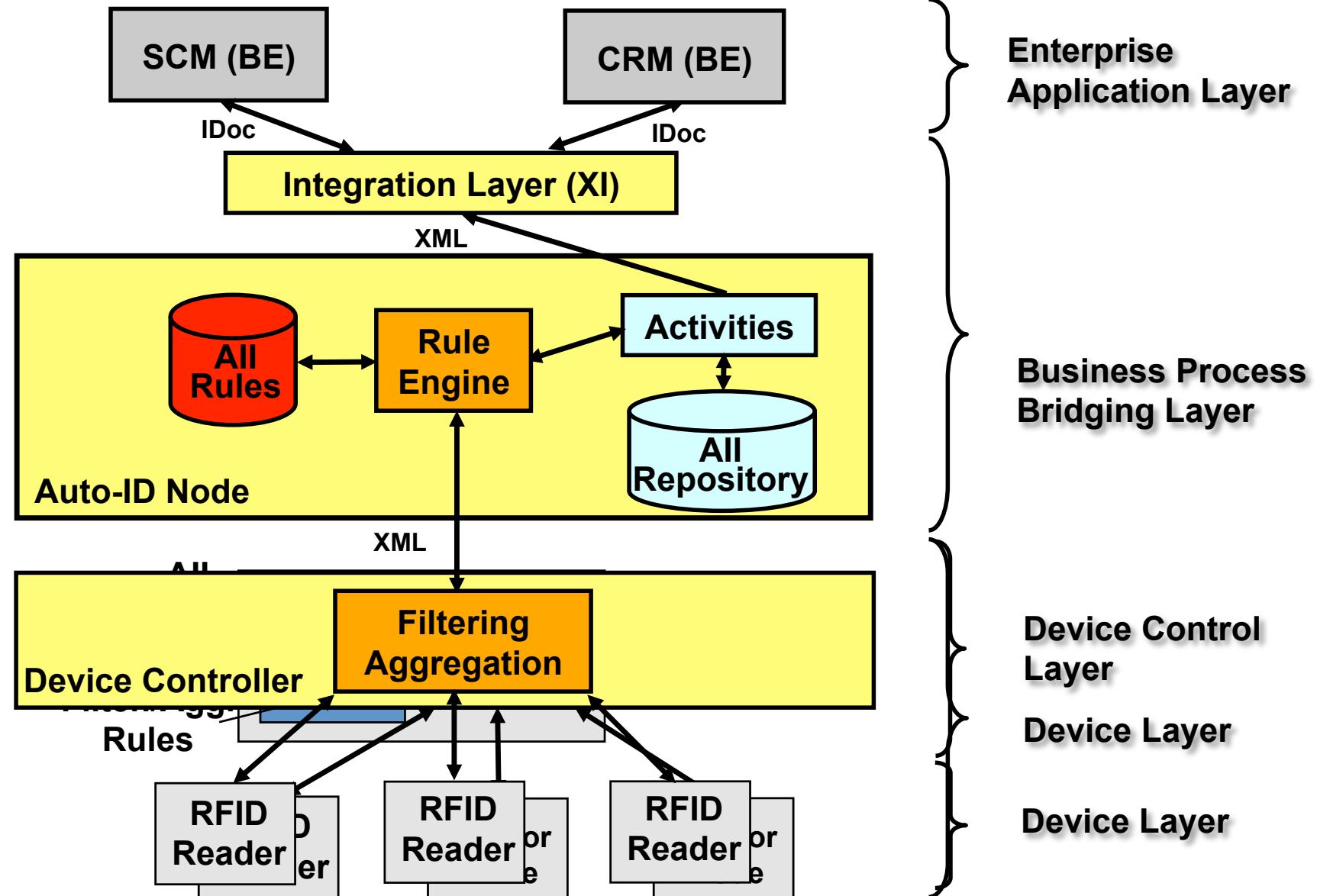
- Exploit local processing power of smart devices:



- to shorten system response time by taking action at the point of observation
- to improve system scalability by reducing data transfer and off-loading workload



AutoID Infrastructure: System Architecture Overview



Fleet Management



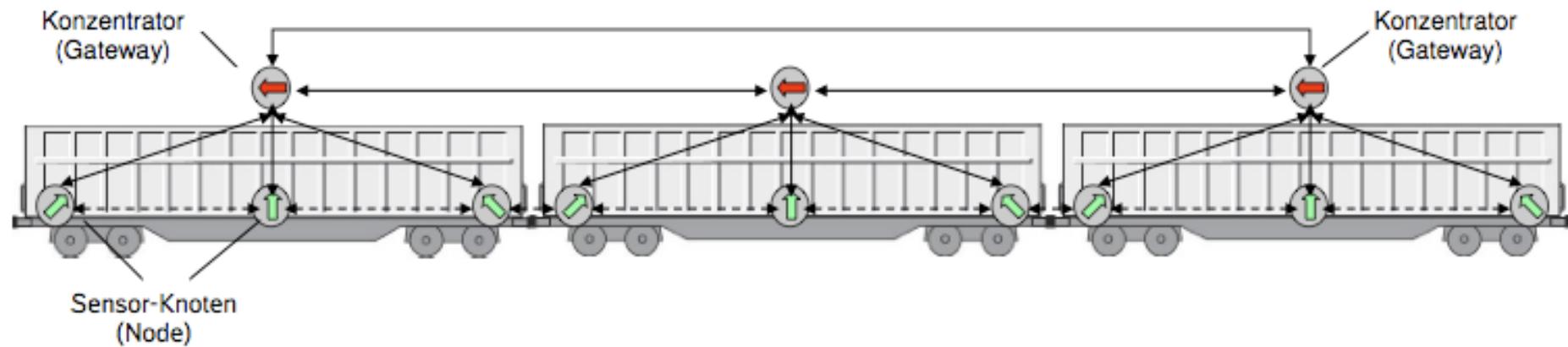
- GPS data
- Driving/resting recordings
- Telemetry...

- Maintenance plans
- Failure warnings
- Early detection of supply bottlenecks in JIT processes



Sensor Networks in Rail Cargo Service

- Large WSN application (90 000 cars, 1 million sensors)
- Long deployment cycles (6 years) – system must function under partial deployment
- Mobility, ad-hoc forming of scopes
- Scopes both static and dynamic
- Location, local WSN (car) all the way to global network



Baggage Tracking

- Bags are tagged, tracked and routed as they pass by readers
- Timing constraints
- Interference
- Risk of false positives (e.g. bag passing near last scanner before loading but on other belt results in major delays)



Piping Information to the Cockpit



- Integrating dynamic information with on-board databases
- Eurocontrol and FAA moving towards free-flight
 - More capacity, same safety
- Reliable delivery of relevant information to cockpit
 - Datalink
 - No spam
 - Reliable delivery
 - Geo-temporal filtering
 - Long events



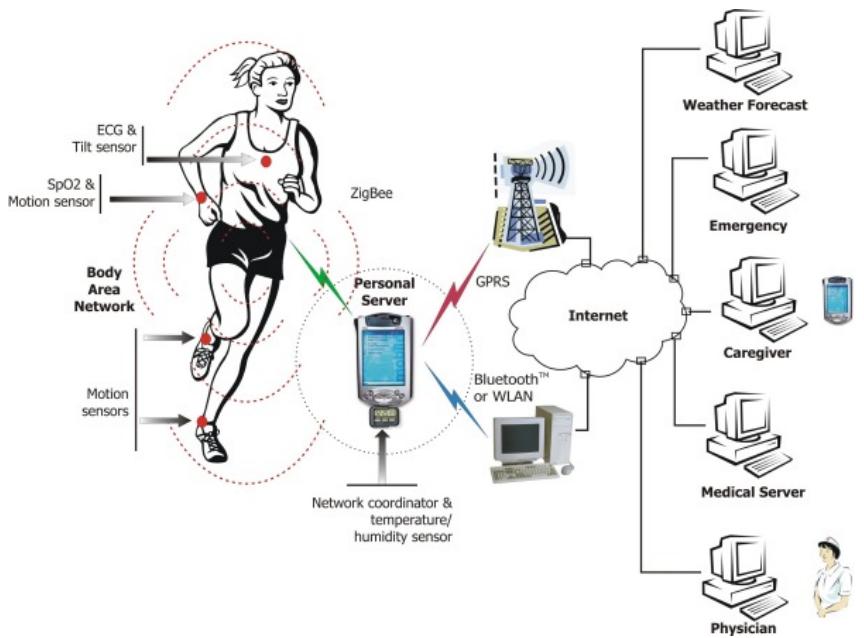
Environmental Monitoring



- Sensor nodes deployed to measure ambient conditions (e.g. discharge T)
- Changes in local conditions are measured and transmitted by WSN
- Local changes are correlated with weather data and forecast models
- Low to moderate volume
- Power generation must be reduced if waste heat raises river T beyond env. safe level



Integrated Health Monitoring



- Wearable sensors
- Body Area Networks
- Wireless transmission in multiple, heterogeneous environments
- Data aggregation along path to central repository
- Extreme heterogeneity
- Extremely sensitive to false positives and false negatives
- Security and privacy issues
- Context dependent security



Ambient Assisted Living



Remove user from critical bandwidth path

- User must control multiple devices depending on context
 - Intelligent objects interact and support the user

Networked intelligent objects interact and support the user

- Human bandwidth is limiting factor and becomes even more precious with aging users
 - Context determines best/most likely option, user selects
 - New event-based specification extends house of interoperable devices
 - Integrated infrastructure → *smart homes* → *smart cities*



Ambient Assisted Living



Remove user from critical bandwidth path

devices depending on context

Networked intelligent objects interact and support the user

Human bandwidth is limiting factor and becomes even more precious with aging users

- Smart networked devices interact: proactive/intentional computing presents options
- Context determines best/most likely option, user selects
 - User must specify context through use of proper device
- New event-based computation models to deal with physical devices
- Integrated infrastructure → *smart homes* → *smart cities*

Smart Cities



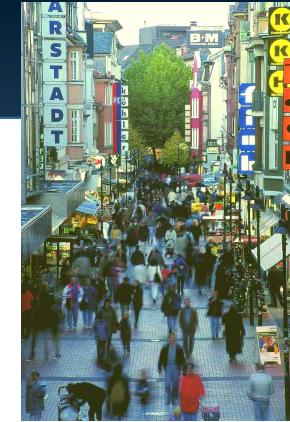
**Elderly person
... leaves home**

- stationary → mobile health surveillance
- communication support → heterogeneous communication
- guidance and assistance for different needs → weather dependent, different locating systems, ...
- single provider → multiple providers, service contracts, ...



... uses public facility

- timetable reading (vision enhancement, speaking timetable...)
- communicating special needs to vehicle/driver
- guided usage (when/how to change)
- uninterrupted health monitoring while on bus



... enters complex environment

- profile based orientation/ navigation
- obstacle detection
- shopping assistance (tagging, pricing, ...)
- emergency response
- authentication/identification support (device overload, interference, ...)

- Composable architectures, device orchestration, interoperability...
- Context changes, privacy requirements, user models, ...
- Intermittent communication, multiple protocols, interference...
- Adaptive mechatronic devices, dependability, mobility,...

**Today's Aml infrastructure is at the same level
that telephony was 100 years ago**



On-line Gaming (e-sports)



- Millions of players worldwide
(World of Warcraft surpassed *11.5 million players*)
- Huge business impact
- Today client/server, tomorrow P2P



- Very demanding application,
huge event streams
- Three key issues:
 - Time-critical delivery
 - Consistency
 - Cheat-controls



Features of Distributed Event Based Systems

- Temporal events
- Absolute position events
- Logical positioning
- Spatio-temporal correlation
- Other context in events
- Change events
- Status events
- Interval events
- Event sequencing/out of order events
- Homogeneous aggregation
- Heterogeneous composition
- Event enrichment
- Derived (higher abstraction) events
- Event re-use
- Event cleansing, outliers
- Early filtering
- Event purging
- Event persistence
- Audit trail
- Event propagation/notification
- Delivery guarantees
- False positives
- False negatives
- Transaction processing
- Point of processing
- Heterogeneity of platform
- Volume
- Security
- Privacy
- Mobility of event source
- Mobility of subscriber
- Mobility of network in between



Platforms for families of DEBS applications

- **Stream processing engines:**

Big iron, centralized, extremely high volume of homogeneous events, event enrichment, on the fly pattern mining

- **Wireless sensor networks:**

Small, self-contained, in-network aggregation, single sink, multihop wireless communication, low volume, don't scale

- **Messaging systems:**

Reliable and high volume message delivery, scalable, filtering/composition/routing in broker network

- **Mixed mode systems:**

From low end sensors to high end servers, result from integration of many (small) applications, extendible, self-X, middleware for isolation, high volume but segmented



Research issues

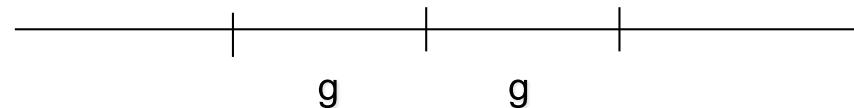
- Event algebra, interval semantics, uncertainty, correlation



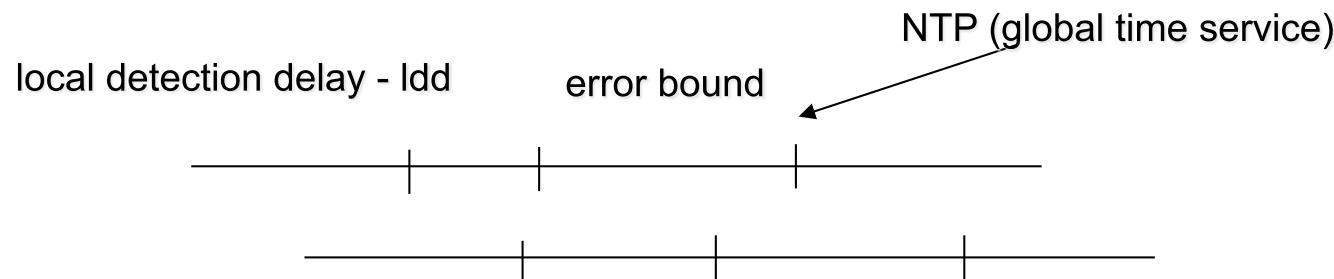
Research issues – Algebra and Correlation

Event algebra depends on assumptions made on

- Duration of events (point vs. interval)
- Ordering (single clock vs. distributed timestamping)
- Uncertainty (clock properties and network delays)
- Granularity of time, middleware shouldn't lie
 - Bounded network delay (2g precedence)



Unbounded network delay (Accuracy interval approach)



Research issues

- Event algebra, interval semantics, uncertainty, correlation
- Event validity, reuse, consumption, purging, long lived events



Research issues – event lifecycle

Event validity, reuse, consumption, purging, long lived events

- **Mechanisms for defining validity intervals**

- Long lived events
 - How to notify new subscribers



- **Consumption policies of events**

- Disappearance of events upon consumption
 - Copy of event instances
 - Removal / garbage collection of events



Research issues

- Event algebra, interval semantics, uncertainty, correlation
- Event validity, reuse, consumption, purging, long lived events
- Enrichment, metadata, combining xSQL with graph semantics



Research issues – Enrichment, Metadata, Languages



- **Event enrichment**
 - Integration of events and external data sources
 - Extraction of events from online sources (e.g. blogs)
 - Metadata for events
 - Event visualization and dashboards
- **Event languages**
 - Combining (X)-SQL and graph based languages



Research issues

- Event algebra, interval semantics, uncertainty, correlation
- Event validity, reuse, consumption, purging, long lived events
- Enrichment, metadata, combining xSQL with graph semantics
- Mobility, replay, forwarding, delivery guarantees, QoS



Research issues – Mobility, delivery, forwarding

- **Mobility causes intermittent connectivity**
 - Event staging
 - Event forwarding
 - Delivery guarantees
 - Replay of past events
 - Ordering upon reconnection
 - Lost events
- **QoS →**
completeness, timeliness (real-t),
staleness, uniqueness, ...



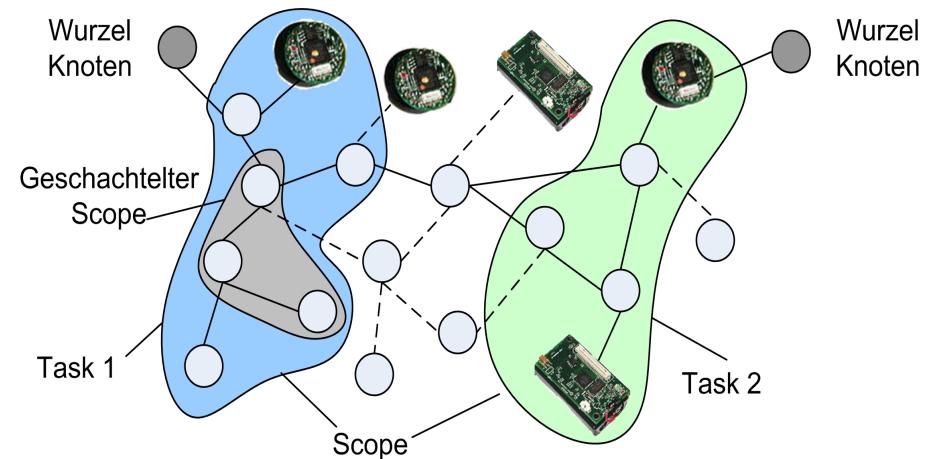
Research issues

- Event algebra, interval semantics, uncertainty, correlation
- Event validity, reuse, consumption, purging, long lived events
- Enrichment, metadata, combining xSQL with graph semantics
- Mobility, replay, forwarding, delivery guarantees
- End-to-end security, scopes, privacy, visibility, routing, QoS



Research issues – e2e security, visibility, privacy

- Structure event space
→ scopes to limit visibility
- Multitasking WSN nodes
- Secure (content based) Pub/Sub
- Privacy policies and enforcement
- Situation aware security



Research issues

- Event algebra, interval semantics, uncertainty, correlation
- Event validity, reuse, consumption, purging, long lived events
- Enrichment, metadata, combining xSQL with graph semantics
- Mobility, replay, forwarding, delivery guarantees
- End-to-end security, scopes, privacy, visibility, routing, QoS
- Dealing with heterogeneity in mixed mode systems, MW capable of spanning widely diverse environments



Research issues – Heterogeneity, mixed mode MW



- Middleware that can function in **mixed mode environments**
- **Self-X properties:** self configuring, self-healing, self protecting
- **Interoperability** management
- **Context** management, ...

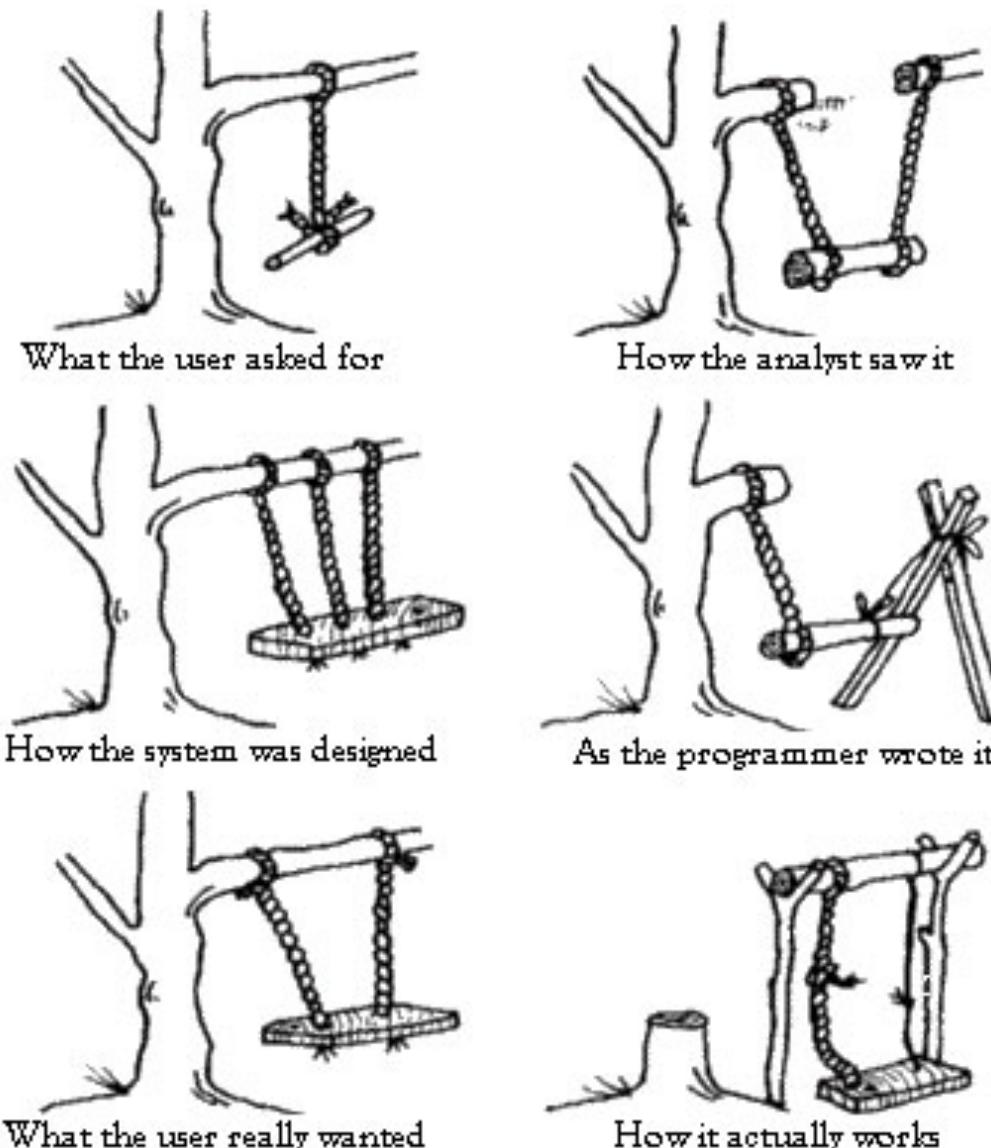


Research issues

- Event algebra, interval semantics, uncertainty, correlation
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- Dealing with heterogeneity in mixed mode systems, MW capable of spanning widely diverse environments
- Software engineering of event based systems



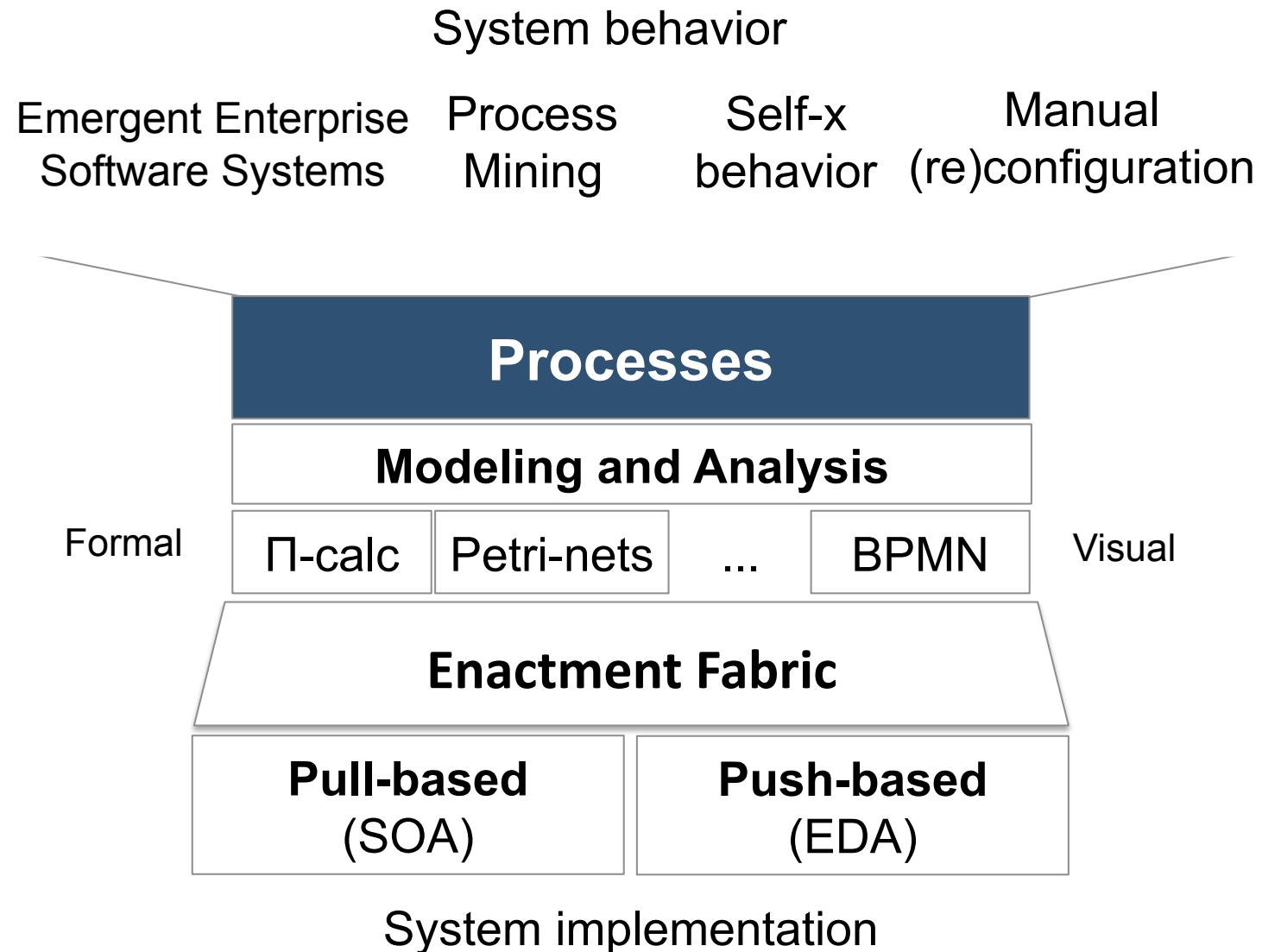
Research issues – SW Engineering



- Event based systems require different requirements gathering
- Correctness criteria, expectation
- Reproducibility while testing
- Long deployment cycles
- Correct/adequate functionality of semi-deployed systems
- Maintenance
- Governance
- Integration of SOA and EDA



Global Architecture for Future BPM



Research issues

- Event algebra, interval semantics, uncertainty, correlation
- Event validity, reuse, consumption, purging, long lived events
- Enrichment, metadata, combining xSQL with graph semantics
- Mobility, replay, forwarding, delivery guarantees
- End-to-end security, scopes, privacy, visibility, routing, QoS
- Dealing with heterogeneity in mixed mode systems, MW capable of spanning widely diverse environments
- Software engineering of event based systems
- Performance modeling and evaluation, benchmarking



Research issues - Performance

- Performance modeling of event based systems is tricky, scalability problems
- Workload characterization
- Beware of single company controlled benchmarks
- Need for reliable and independent benchmarks



Outlook

- Many of today's most interesting applications are distributed (cyberphysical) event based systems
- There are **MANY** interesting (research) problems in DEBS
- Solving some of the fundamental (research) issues are necessary condition for a broader acceptance of DEBS
- There is a deficit in the preparation of *professionals capable of designing, developing, deploying and operating event based systems*



Acknowledgements

- Annika Hinze, Kai Sachs: analysis of applications
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