Event-driven systems

Event-driven communication paradigm

- asynchronous message-passing rather than request-reply
- advertise, subscribe, publish/notify for scalability

  e.g. subscribe to and be notified of:

  bus-seen-event (busID=uni4., location=*)*
- event-driven paradigm for ubiquitous computing: sensors generate data, notified as events
- compose/correlate events for higher level semantics

  e.g. traffic congestion, pollution and traffic
- database integration – how best to achieve it?

Event-Driven Systems CEA

Cambridge Event Architecture (CEA), 1992 -

- extension of O-O middleware, typed events
  - "advertise, subscribe, publish/notify", direct or mediated,
  - publishers (or mediators if >1 publisher for a type) process subscription filters and multicast to relevant subscribers
- federated event systems:
  - gateways/contracts/XML
- applications:
  - multimedia presentation control
  - pervasive environments (active house, active city, active office)
  - tracking mobile entities (active badge technology)
  - telecommunications monitoring and control

Event-Driven Systems - Hermes

- Hermes large-scale event service, 2001-4
  - PhD work of Peter Pietzuch at CL

- loosely-coupled
- publish/subscribe
- widely distributed event-broker network
- via a P2P overlay network (DHT e.g. Pastry), see slide 5
- distributed filtering (optimise use of comms.)
- rendezvous nodes for advertisers/subscribers

Use of P2P/DHT substrate

- Broker IP addresses hashed into 128-bit space
- Event topics hashed into 128-bit space. Topic is managed by broker with nearest value > topic hash
- Brokers keep tables of nearest neighbours (for different common prefixes) in 128-bit space – see next slide
- Event messages from pubs and subs routed to broker nearest to event topic's hash value in O(logN) hops – called the "rendezvous node" for that topic
- Paths to same destination converge quickly
- Paths shared to nearby destinations – late fanout
- Resilient to join/leave/failure of nodes
- Scales to millions of nodes

Pastry node 2030xx…'s routing table starts:

0* **Id,a**	**1*** **Id,a**	**2***	**3*** **Id,a**
20*	**21*** **Id,a**	**22*** **Id,a**	**23*** **Id,a**
200* **Id,a**	**201*** **Id,a**	**202*** **Id,a**	**203***
2030* **etc.**	**2031*** **Id,a**	**2032*** **Id,a**	**2033*** **Id,a**

e.g. route to **1**xxxx…

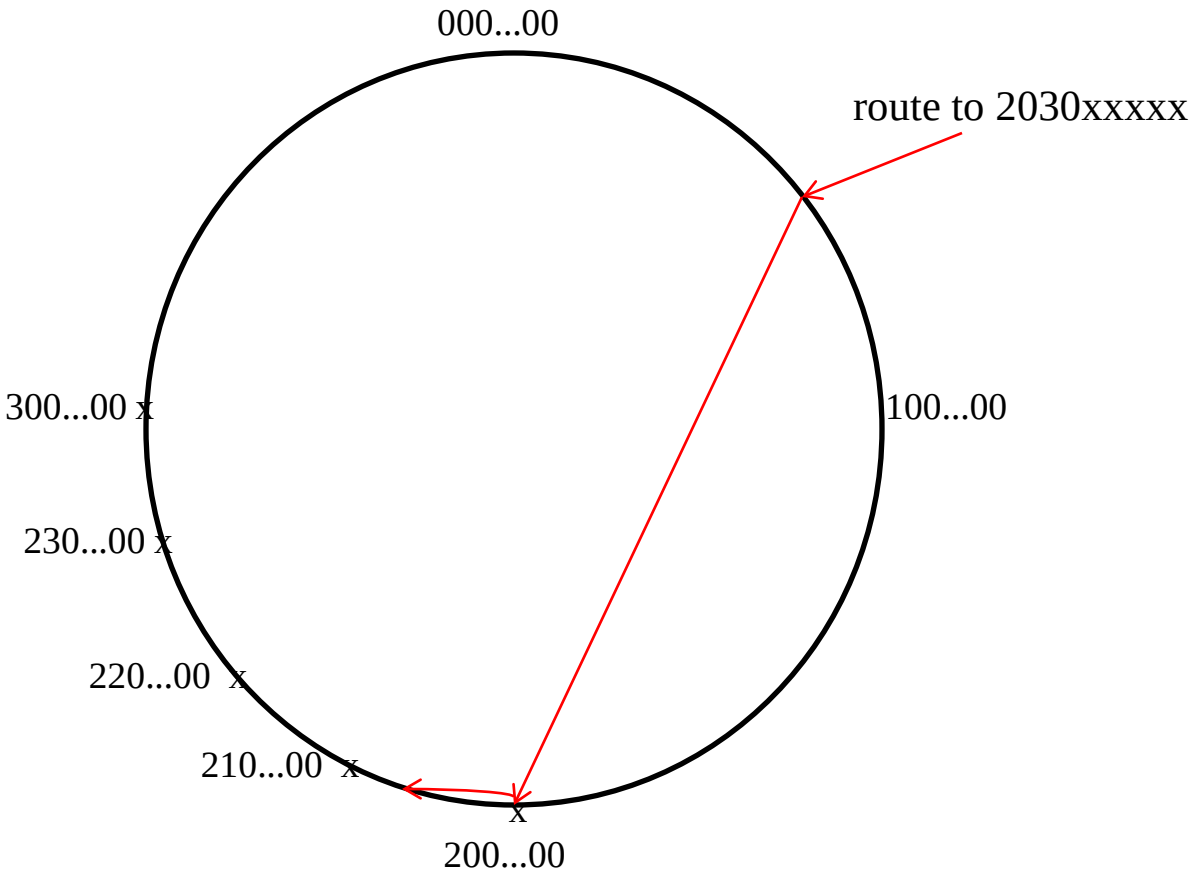
e.g. route to **22**xxx…

e.g. route to **200**xxx…

e.g. route to **2032**xx…

- nodeIds and keys are in some base 2^b (e.g. b=2 here)
- each entry, except those for itself, contains the 'Id' and IP address 'a' of another node

Pastry route convergence, e.g.using base 2



Hermes Pub/Sub Design

- Event Brokers 

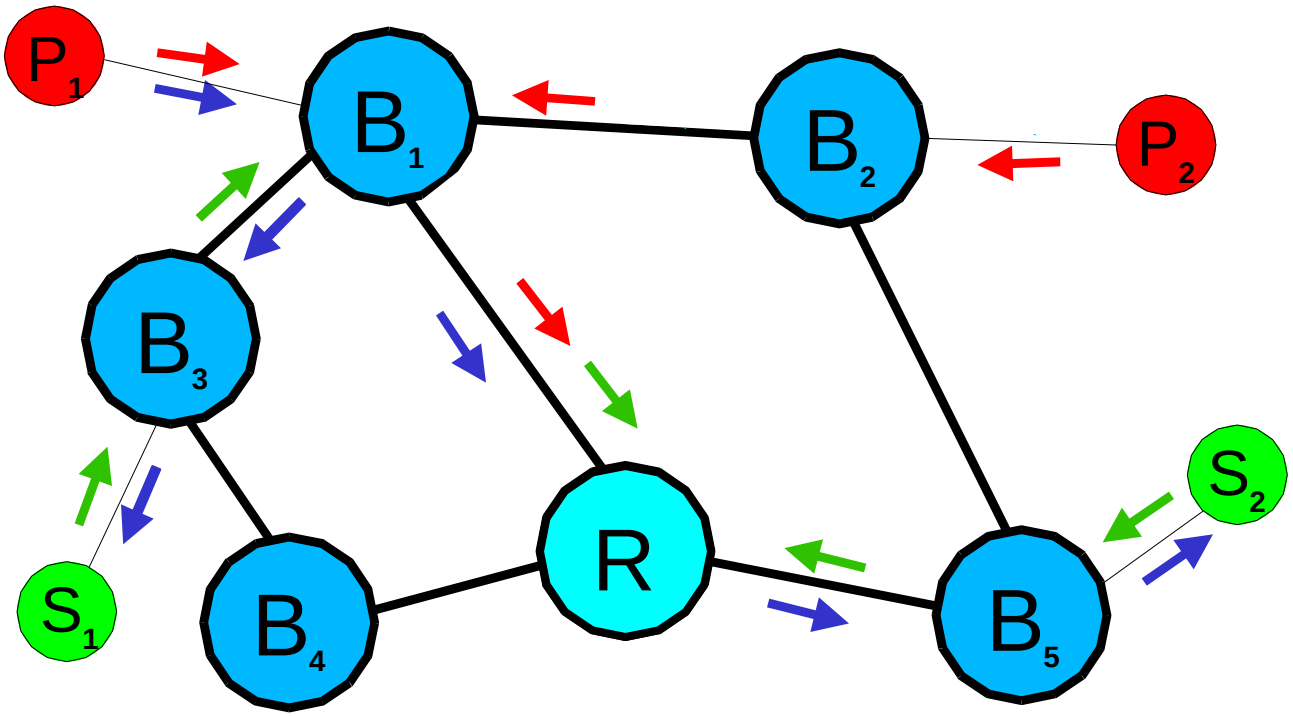
  - provide middleware functionality
  - logical overlay P2P network: content-based routing+filtering
  - easily extensible
- Event Clients: Publishers 

, Subscribers 

  - connect to any Event Broker
    - publishers **advertise**,
    - subscribers **subscribe** (brokers set up routing state),
    - publishers **publish**,
    - brokers route messages and **notify** publications to subscribers
  - lightweight, language-independent

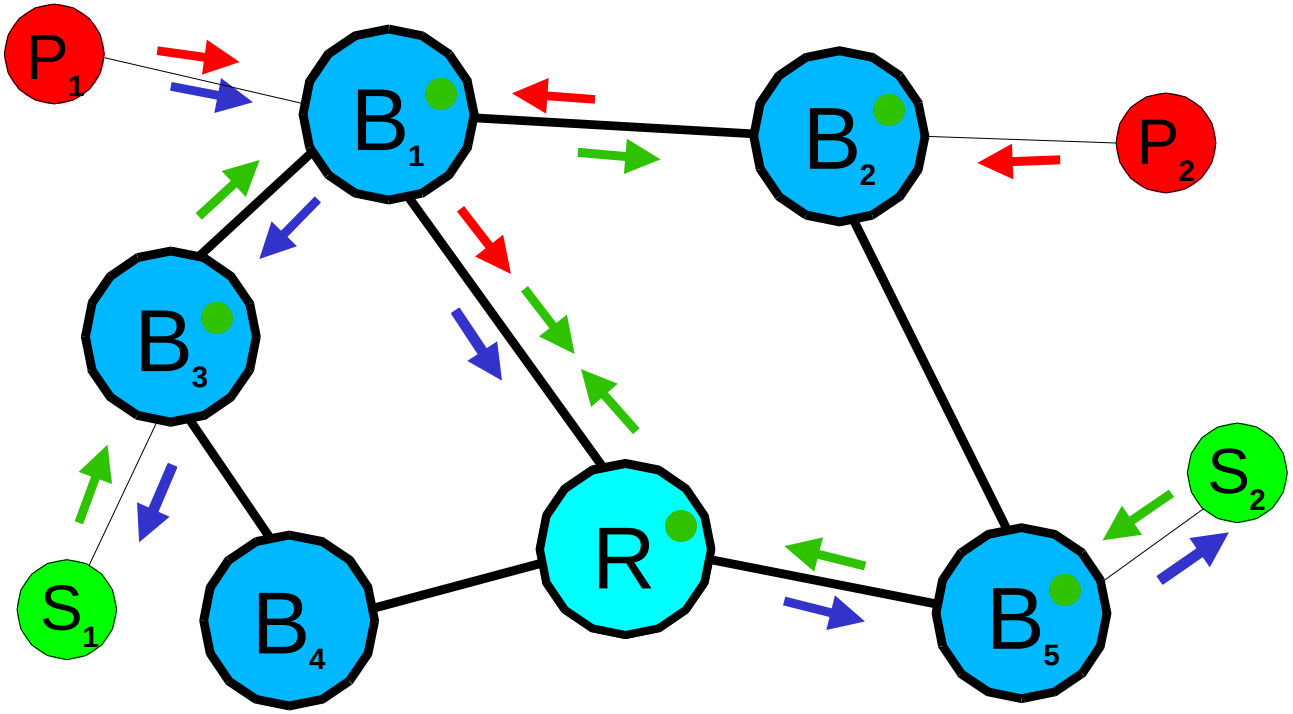
Algorithms I – Topic-Based Pub/Sub

- Type Msg, Advertisements, Subscriptions, Notifications
- **Rendezvous Nodes**
- **Reverse Path Forwarding**
  - Notifications follow Ads then the reverse path of Subs



Algorithms II – Content-Based Pub/Sub

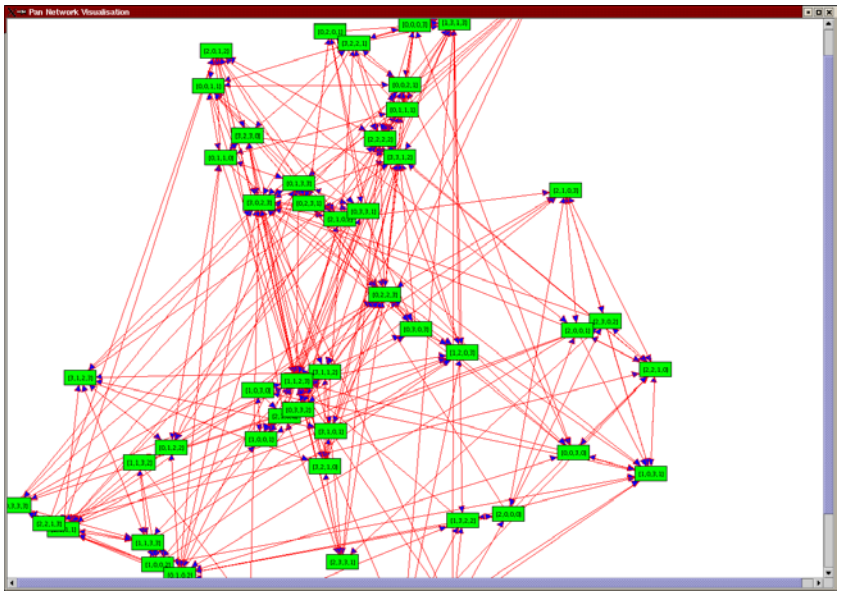
- Filtering State ●
- Notifications follow reverse paths of subscriptions
- Subscriptions consolidated by covering and merging for path sharing before late fanout



Hermes Implementation

- Actual implementation
  - Java implementation of event broker and event clients
  - Event types defined in XML Schema
  - Java language binding for events using reflection

- Implementation within a simulator
  - Large-scale, Internet-like topologies
  - over 100 nodes
  - used in later projects



Pub/sub not sufficient for general applications

- decouples publishers and subscribers
  - pubs and/or subs need not be running at the same time
- publishers are anonymous to subscribers
  - subs need to know topic (attributes), not pubs' names and locations
  - but receivers may **need** to know the sender or sender's role
- only multicast, one-to-many communication
  - may also need one-to-one and request-reply
- can't reply
  - either anonymously, e.g. to vote, or identified (can be fixed)
- efficient notification for large-scale systems using CBR
  - but content-based routing may violate privacy of information
  - subscriptions may also be confidential

Event-Driven systems – Composite Events

- Event composition (correlation)
  - Pietzuch, Shand, Bacon, Middleware 2003, and IEEE Network, Jan/Feb 2004

- composite event service above event brokers
- service instances placed to optimise communication
- FSM recognisers – parallel evaluation
- events have source-specific interval timestamps
- simulations of large-scale systems…

Bottom-up and/or Top-Down?

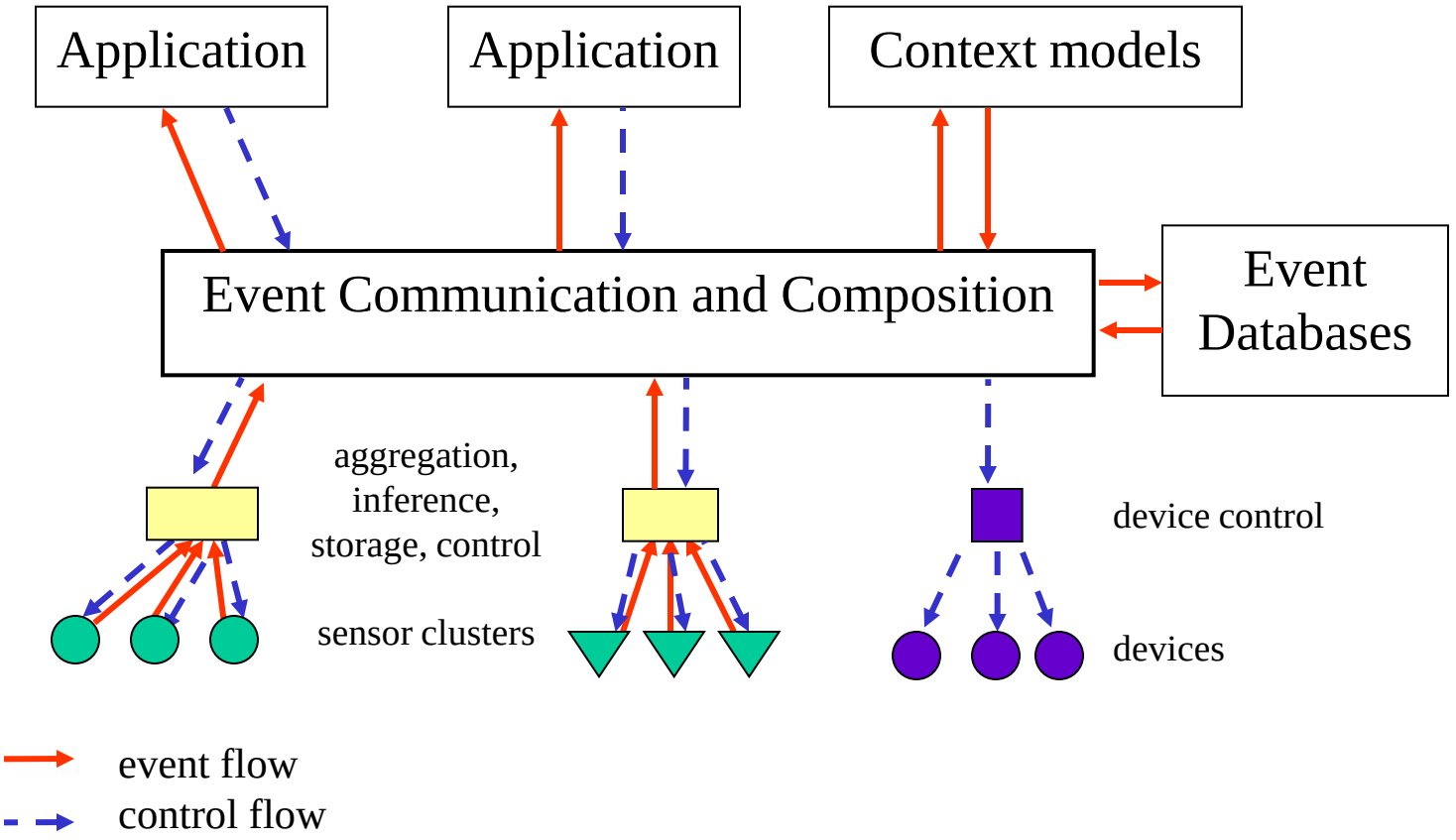
- Can we express all we require by bottom-up composition of primitive events?
- Can we take advantage of high-level models of context?
  - e.g. maps, plans, mathematical models, GIS
- What can users be expected to express?
- How is the *top-down, bottom-up gap* bridged and high-level requirements converted into event subscriptions?

"nearest empty meeting room?", "turn off the lights if the room is empty", "quickest way to get to Stansted airport?"

Work-in-Progress

In 2010, *Dagstuhl seminar in May, DEBS in Cambridge in July*

Integrating sensor networks (1)



Integrating sensor networks (2)

- ***Data*:**
  - sensor-ID, data value, timestamp, location
  - value aggregation from densely deployed sensors
  - inaccuracies masked – data cleansing
  - heterogeneous sensor data correlated (fused)
- ***Information/semantics*:**
  - events defined, to present sensor data to applications including context models
  - events correlated, higher-level events generated
  - real-time delivery may be required
  - level of data logging required (keeping all sensor data)?

Traffic monitoring applications

- ***sensors:***
  - SCOOT loops for counting,
  - video cameras – extract and transmit anonymised data
  - thermal imaging (infra-red detectors),
  - acoustic detectors
  - bus location data
  - car-park occupancy detection
  - ANPR automatic number-plate recognition

- I subscribe to
  - *bus-seen-event* (*busID*=uni*4.**, *location=MadingleyP&R*)

  and my desktop is pinged when the bus is detected.

Traffic monitoring applications (cont'd)

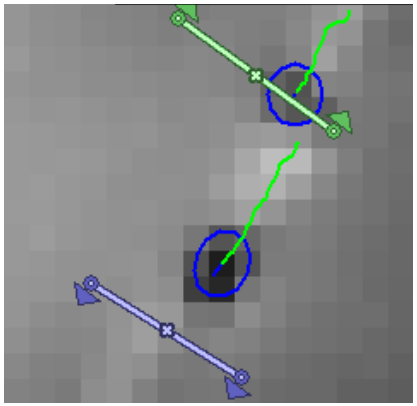
- Route-advice service: on entering my car I indicate my destination on a map – route is shown, car monitored and route updated dynamically as conditions change.

  Research on sharing of data within SatNav systems.
- Easy to do with bespoke systems and/or coupling applications with sensors in "vertical silos" e.g. car park data only sent to displays on radial roads into cities
- Sharing of (public) data: application developers (and public) can build services by subscribing to advertised events

Work-in-Progress: TIME-EACM project

Irisys infra-red cameras + motion detection

- combined with video for validation
  - (and banal tasks like positioning the lines)
- privacy-preserving
- Testing carried out: Dept. Eng. roof, Fen Causeway, 2006
  ~ 90% accuracy cf. video
- wired communication via Engineering Dept.



Irisys – mirroring annual manual count

- carried out on Cambridge radial roads annually
  - we did Huntingdon Rd, 9th Oct 2006, 8am – 7pm
  - using one of DTG's sentient vans
  - amateur positioning (by us)
  - incoming and outgoing traffic
  - validated against video
  - over 90% accuracy cf. video if cycles excluded
- County Council haven't told us how their manual count compares with video

Irisys – ongoing monitoring

- mounted on a lamp post on Madingley Road
- connection to CL via Wifi

Stagecoach/ACIS bus monitoring

- GPS location of buses on some Stagecoach routes
- radio transfers data back to base
  - some GPRS, some custom
- bus-stop displays
  - timetables and expected arrival times
  - Minibus project – mobile phone selection of bus stops and display of information
- live and historical data from ACIS since Aug 2007
  - for project use - under a NDA
- this data allows journey times and congestion to be analysed and predicted

Healthcare monitoring application

sensors: body sensors for blood-pressure, blood-sugar, etc.
cameras / thermal imaging in smart homes, tag objects

- Emergency detection based on sensor values and image analysis – how to decide when to summon help?
- Smart homes: monitoring for falls, visitors, …
  - (guide-dogs–vs–people?) (visitors–vs–burglars?)
- Tagging objects: "where did I leave …?", (*pull* model)
  or to build a world model for navigation avoiding obstacles
- Economic model? cost of technology–vs–more people? risks/costs of false positives and false negatives?

- **Work-in-Progress: CareGrid and PAL projects**

Integrating databases with pub/sub

- DB world: continuous queries require recording of individual queries and individual response, one-to-one.
- instead, Event-Based world: databases advertise events
  - *event type* (*<attribute-type>*)

  e.g.“cars-for-sale(maker, model, colour, automatic?, …)”

  advertised by many databases e.g. in the Cambridge area
- clients subscribe and are notified of occurrences
- the pub/sub service does the filtering – not the database
- we have used PostgreSQL – active predicate store

DB Motivating Example – Police IT

Bill Hayden is suspected of masterminding a nationwide terrorist organisation.

- As well as looking up his past database records, the investigators (special terrorism unit) **subscribe**, in all 43 police counties, to **advertised** database update events specifying his name as an attribute.
  - *Note inter-domain naming and access control.*
- Triggers are set in the databases so that any future records that are made, relating to his movements and activities, will be **published** and **notified** automatically and immediately to *those authorised* to investigate him.

Securing pub/sub using RBAC

- At the event client level – use RBAC
  - domain-level authorisation policy indicates, for event types and attributes, the roles that can advertise/publish and subscribe
  - inter-domain subscription is negotiated, as for any other service
    - note that spamming is prevented – only authenticated roles can use the pub/sub service to advertise/publish
- At the event-broker level – use encryption
  - are all the event brokers trusted?
  - if not, some may not be allowed to see (decrypt) some (attributes of) some messages.
    - this affects content-based routing

Work-in-Progress – SmartFlow project