Message Models and Aggregation in Rich Sensor Systems

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Project Focus

- Messaging middleware for rich sensor systems
  - Closer to (semantic) sensor webs than sensor nets
    - Diverse sensors generating (large) artifacts to distribute
  - Several important differences from both
    - Mobile, decentralized, self supporting
    - Sensing via proactive agents or reactive services
    - Effectors, databases, and other services mixed in

Semantic Addressing

- Knowledge-based, ontology driven messaging
  - Declarative descriptions of messages, destinations
    - Apply description logics, leverage Semantic Web
  - E.g., annotating detected nuclides in CBRN application:

```
<cbr2:N4242Spectometry rdf:about="#MSG1134">
  <msg:source>
    <cbr2:Fixed-FT-IR rdf:about="#Sensor03NG">
      <msg:org rdf:resource="&orgs;#NEAir-Haz" />
    </cbr2:Fixed-FT-IR>
  </msg:source>

  <cbr:nuclideDetected>
    <cbr2:Am-241>
      <cbr:confidence>93.0</cbr:confidence>
      <cbr2:concentration>0.002</cbr2:concentration>
    </cbr2:Am-241>
  </cbr:nuclideDetected>
</cbr2:Spectometry>
```

  - E.g., subscribing to position reports in C2 app:

$$\text{PositionReport} \sqcap \exists \text{source} . [\, \text{SquadLeader} \sqcap \exists \text{location} . \text{Checkpoint-A-Region} \,]$$

- Goal: Interoperability, extendability, flexibility via loosely coupled, declarative message exchange

Message Models

- Interested in explicit models of messaging types
  - Ontology of message/middleware behavior
- Several applications
  - Better understand our requirements, other systems
  - Service specification language or API
  - Side interest: Automated declarative gateways bridging middleware networks of varying capability

Delivery Models

- Delivery model aspects of messages are traditional networking and QoS categories
  - Best effort, reliable, persistent
  - Unicast, broadcast, multicast, (exactly-one) anycast
- Some interplay with addressing models
  - E.g., if messages are addressed with queries then unicast differs little from exactly-one anycast

Addressing Models

- Need to support both publications and requests
  - Two different addressing or matching models
- Receiver querying: Destinations register queries for messages

$$\forall\,(m,m',d)\in M,\ (p,q)\in D$$
$$\left[d \bigwedge_{b\in B} b \models q(m')\right] \Rightarrow (m,p)\in dest$$

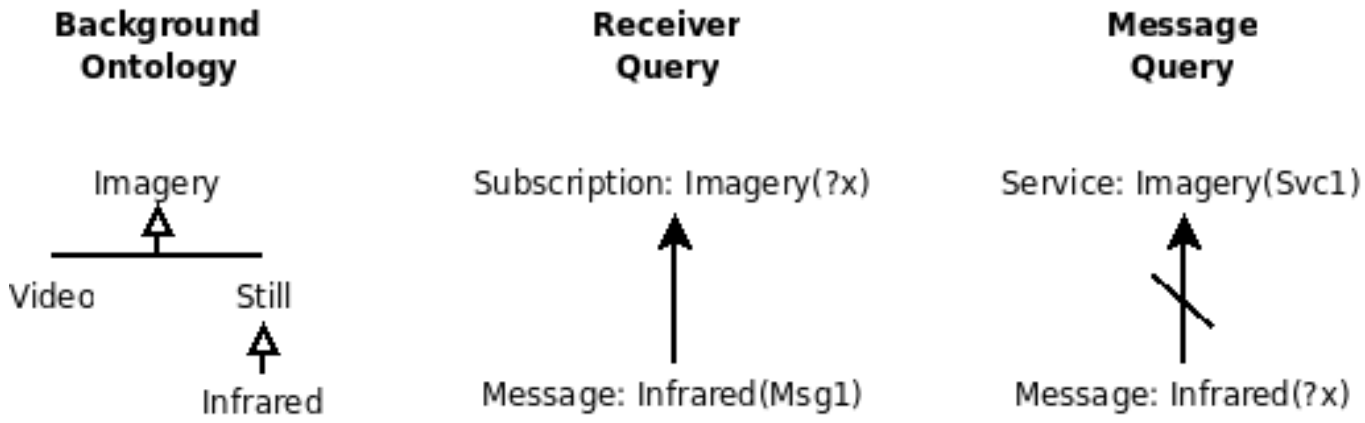
  - Aligns with publications or announcements
  - Expressive publish/subscribe model
- Message querying: Messages include queries for destinations

$$\forall\,(m,q)\in M,\ (p,p',d)\in D$$
$$\left[d \bigwedge_{b\in B} b \models q(p')\right] \Rightarrow (m,p)\in dest$$

  - Aligns w/ requests; not commonly supported

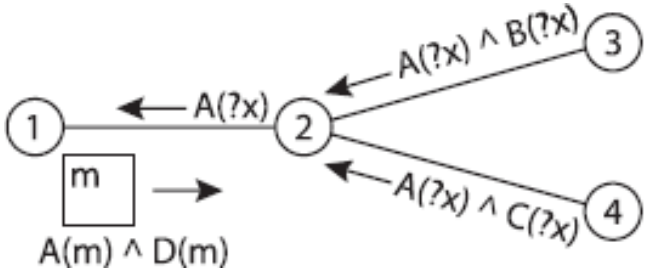
Receiver vs Message Querying

- Difference is control of sufficient conditions
  - Both match future extensions, specializations
  - Receiver query delivers to any interested entity
  - Message query imposes requirements that recipient must match, i.e., in order to fill request

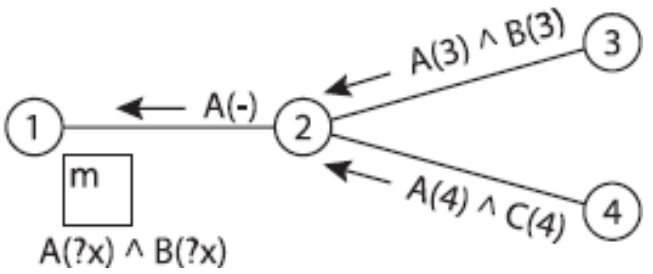


Aggregation

- Different, significant effects on aggregation
  - Aggregating receiver queries creates false positives
  - Aggregating message queries produces false negatives; this is probably much worse



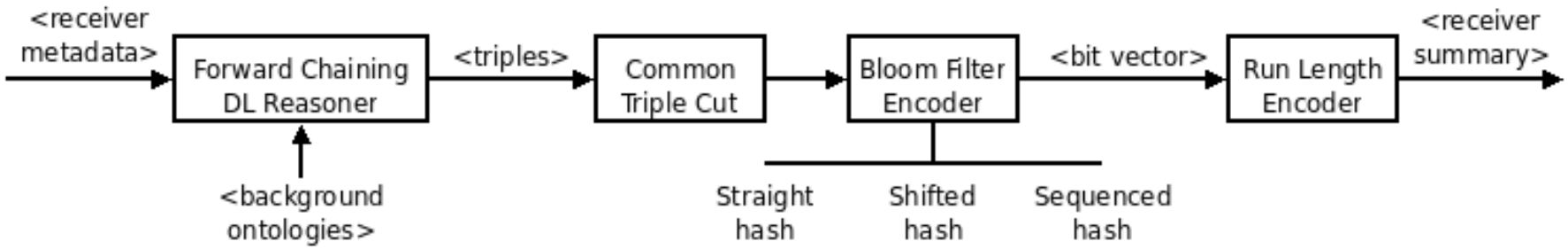
Receiver Query



Message Query

Message Query Aggregation

- Need to aggregate receiver metadata such that false negatives are not potentially produced
- Approach: Convert metadata to Bloom Filters
  - Bit vector summary of entailed triples



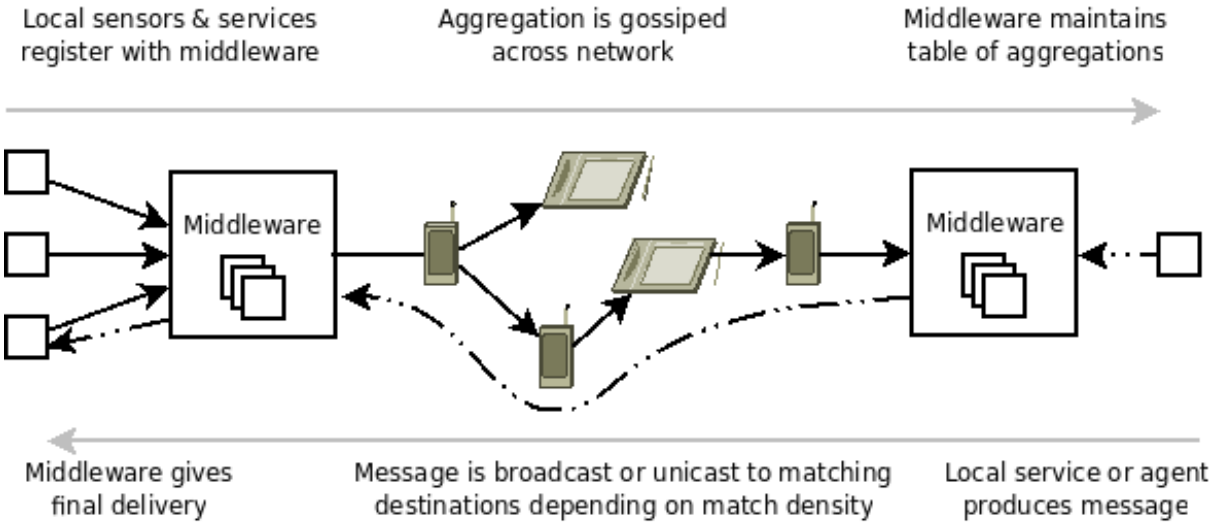
  - Queries also converted to bit vectors for matching
  - Aggregation by bitwise-or, matching by bitwise-and

Bloom Filter Metadata Summaries

- Several advantages:
  - Produces false positives instead of false negatives
  - Easily aggregated and matched
  - Compact and of finite, parameterizable size
- Many disadvantages:
  - Expressivity limits
  - Reduced interoperability
  - Inference only at receiver; must have all ontologies
    - New background must be globally shared, updated

Usage: Simple Gossip Framework

- Difficulty of robustly maintaining even simple structures on mobile networks is a large issue
- Aggregated registrations shared via gossip, locally matched, forwarded via transport layer
  - Possible by aggregation, manageable # of nodes (<100s) and natural clustering in our scenarios (PAN/LAN groups)



Summary & Future

- Most current middleware does not address all message models required in these systems
  - I.e., message query style requests
- Scheme presented here is a new combination of Bloom Filters and ontology-driven reasoning
  - Related to work on Bloom Filters for P2P, DBs
- Current focus on expressiveness, practicality
  - Usefulness of filter scheme is hard to gauge---very dependent on application ontologies, expressivity

End

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