Monitoring and Testing for Reliable Smart City Applications

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Agenda

Introduction
- CityPulse Framework

Reliable Smart City Application
- Travel Planner

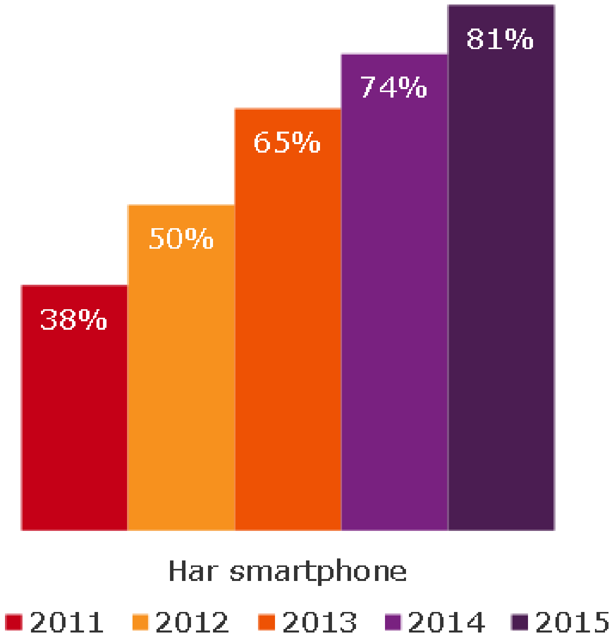
Testing Concept

Monitoring Concept
- Atomic Monitoring
- Composite Monitoring

Conclusion

Introduction

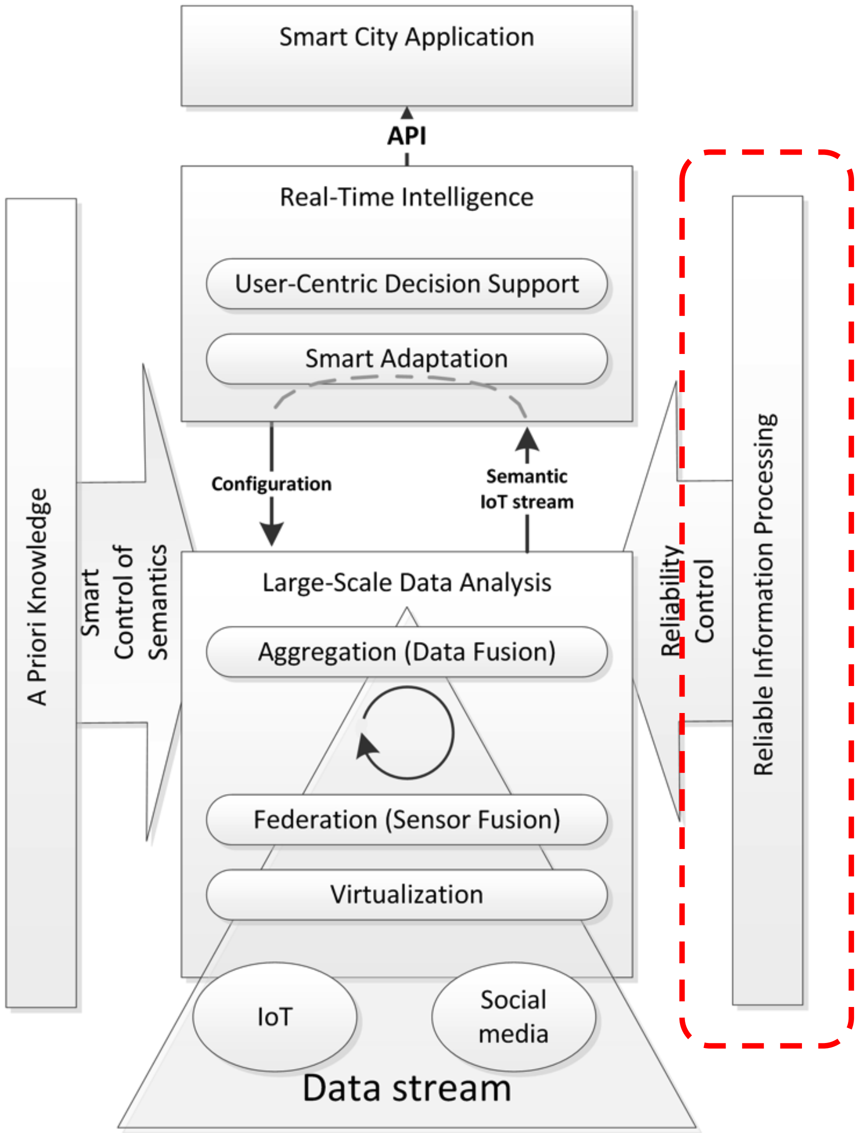
- Smartphone distribution increasing
- Germany > 50%
- Denmark:



- New applications to enhance life of citizens
  - Simple (weather or pollution forecasts), Complex (shopping planner with integrated user preferences, e.g. “avoid pollution”, “use scenic routes”)

CityPulse Framework

- Architecture of CP-Framework
  - Virtualisation
  - Federation (Sensor Fusion)
  - Aggregation (Data Fusion)
  - Smart Adaptation
  - User Centric Decision Support
  - Reliable Information Processing
  - Smart City Applications



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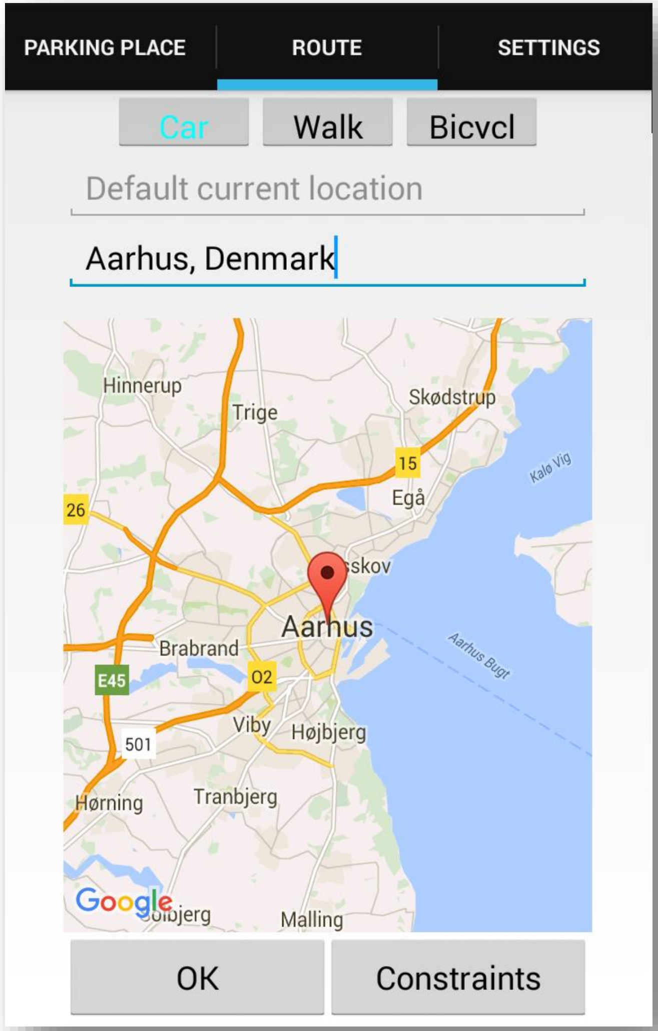
Reliable Smart City Application

- Travel Planner application
  - Asks user for destination in Aarhus, selects near parking garage with free parking slots
  - Contains features to constrain routing process by user preferences
  - On the fly route changes if events detected by CP-framework
  - Highly depended on used data sources
    - CP-QoI-Monitoring components allow real-time Quality Monitoring for data streams
    - Data sources annotated with semantic annotation, allows reasoning and conflict resolution
- Prone to faulty data delivered by used data streams
  - Faulty data requires complex application testing before deployment
  - Applications may require certain QoI levels
  - Testing of applications with degenerated data streams will result in minimum QoI requirements for applications



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Testing

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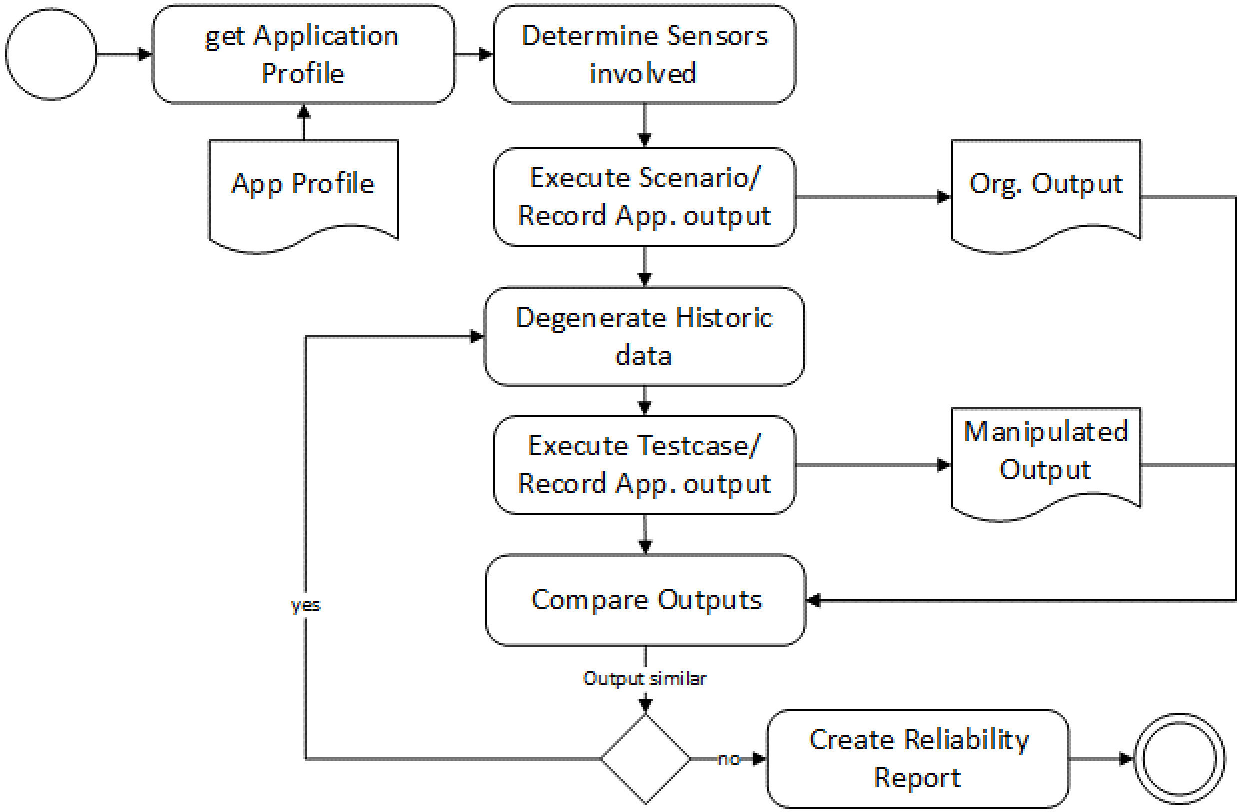
- Goal: evaluate reliability of smart city applications
- Problem: no ground truth for datasets available
  - Collected data for December 2015 used as reference dataset
- Approach:
  - Determination of required data streams/sensors
  - First testcase T_0
    - Output of CP-framework used as ground truth
  - Testcase T_n
    - Degeneration of input data
    - Output compared to output of further tests
    - Passed if distance between T_n and T_{n-1} is below a threshold



Testing

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- Generation of test case stimuli:

```
1. While τ = A + (r * tick) < Ω:
2.  For each sensor s in S:
3.   v = H(s, τ)
4.   For each error e in E:
5.     If (P_e,s = true and e not active)
6.          activate e
7.     v' += apply e on v if e is active
```

- v‘ substitutes historic values in H to form a new testcase
- Process is repeated n times
  - Set of testcases with decreasing (more unreliable) stream data

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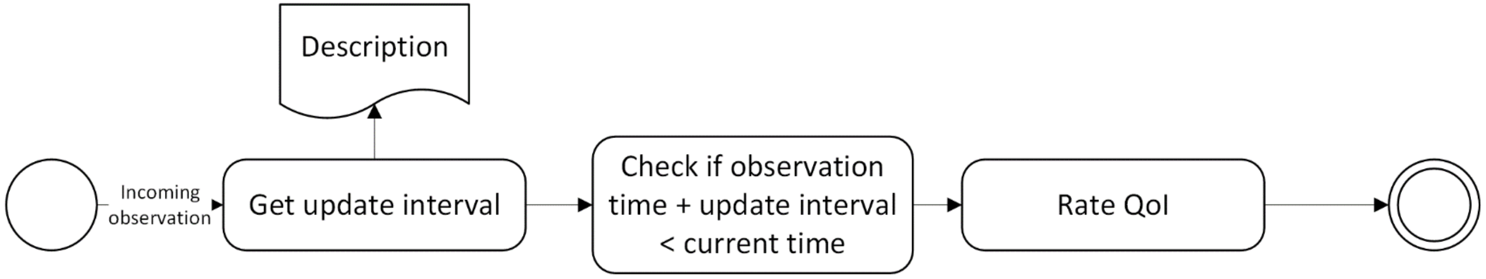
Monitoring Concept

- Smart city applications depend on
  - appropriate,
  - accurate,
  - trustworthy
  - … data streams
- Data stream reliability has to be monitored in real-time
- Monitoring methods compare data stream QoI with required QoI level for application
- To fulfil real-time requirements CP-Monitoring is split into two components
  - Atomic Monitoring
    - Rudimentary QoI check for single data streams
    - Real-time sanity checks
  - Composite Monitoring
    - Validation of detected events by investigating correlation between spatial-correlated streams
    - Computationally complex

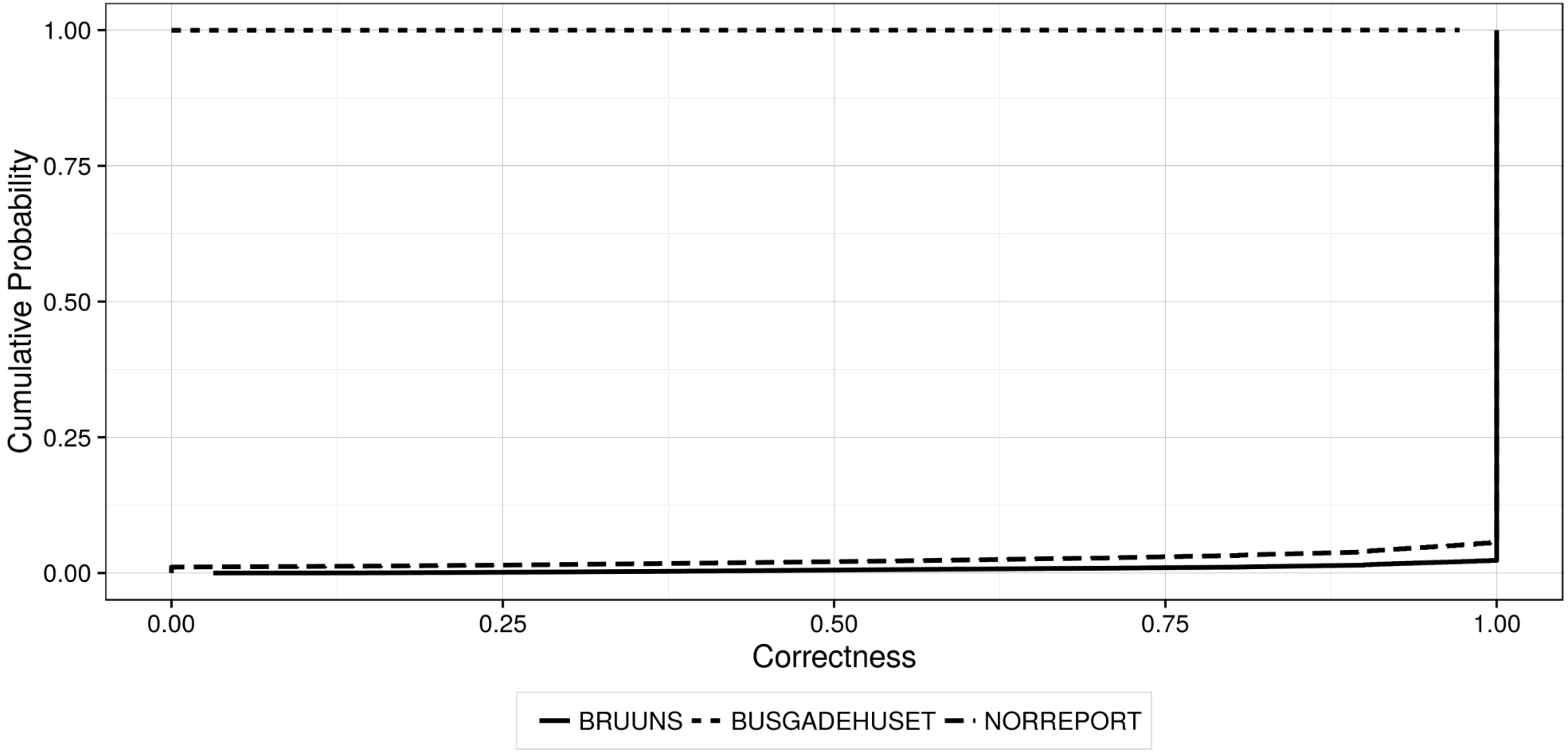
Atomic Monitoring

- ❑ Real-time QoI annotation of incoming sensor observation from data streams
- ❑ Directly integrated into Data Wrapper of stream
- ❑ Includes only basic QoI checks based on a stream description
  - Age



  - Completeness
  - Correctness
  - Frequency
  - Latency

- Results
  - Experiments done with Parking and Traffic data stream for Aarhus (December 2015)
  - Parking



Atomic Monitoring

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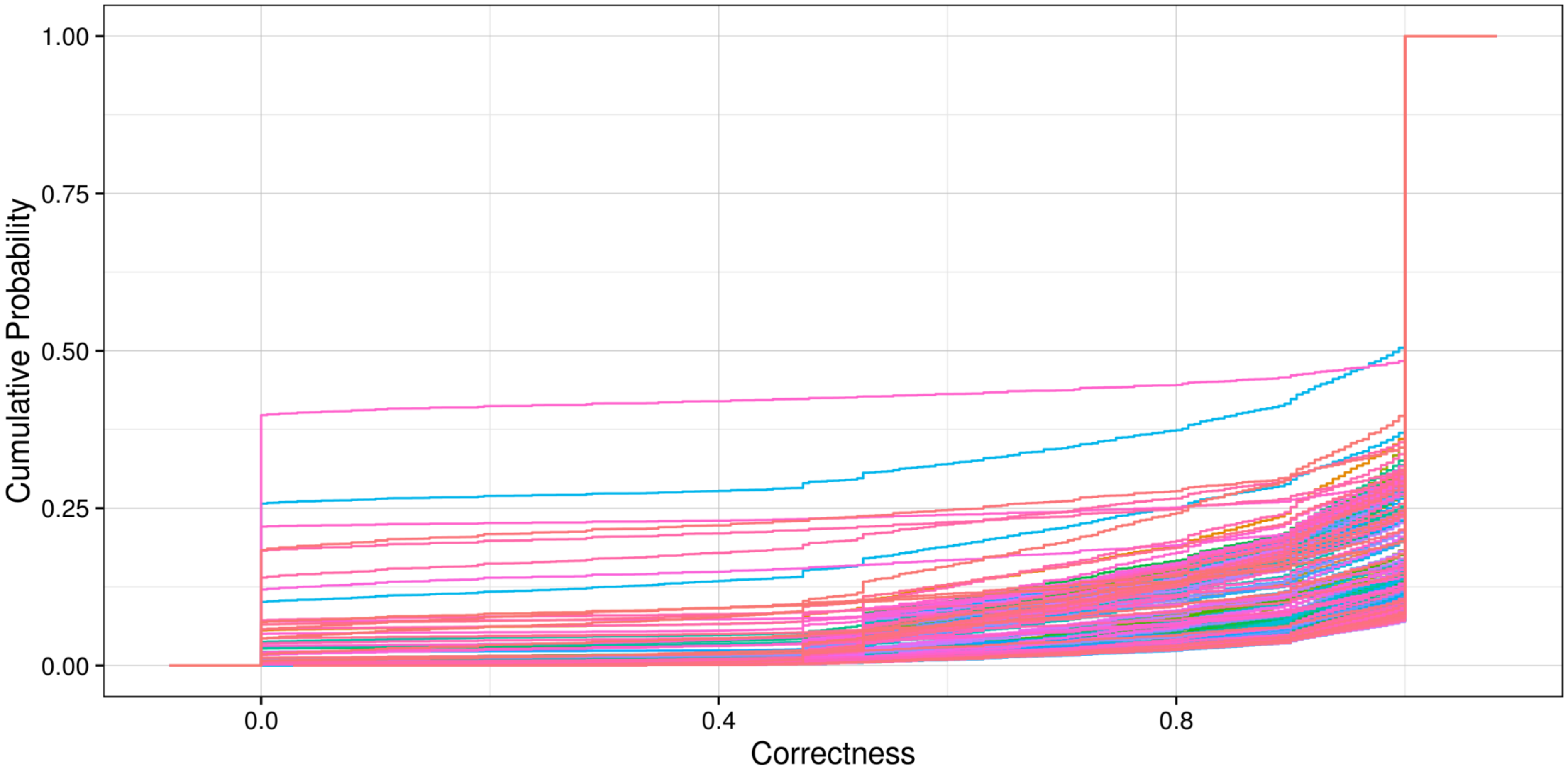
- Traffic Correctness



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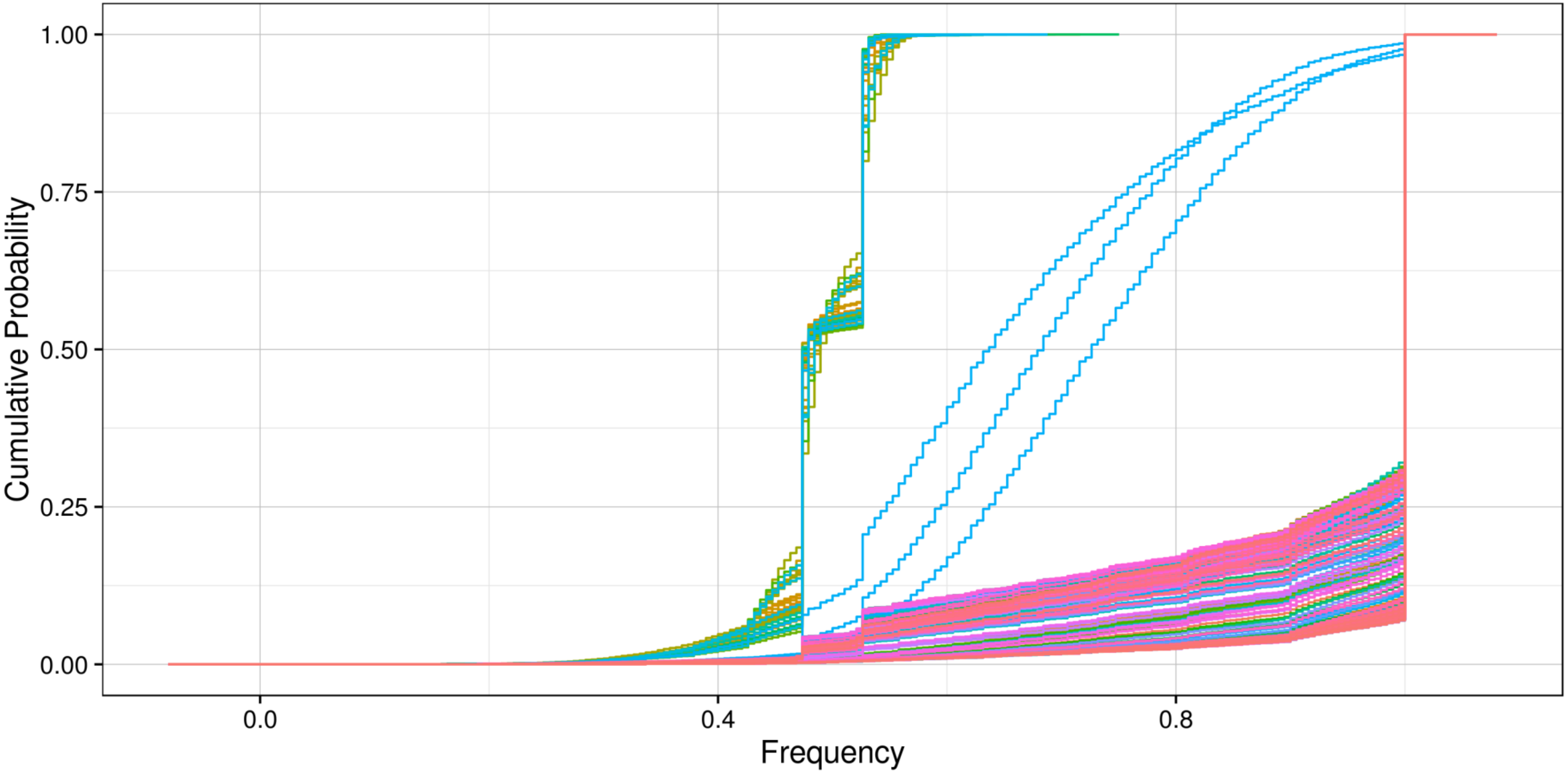
- Traffic Frequency



Atomic Monitoring

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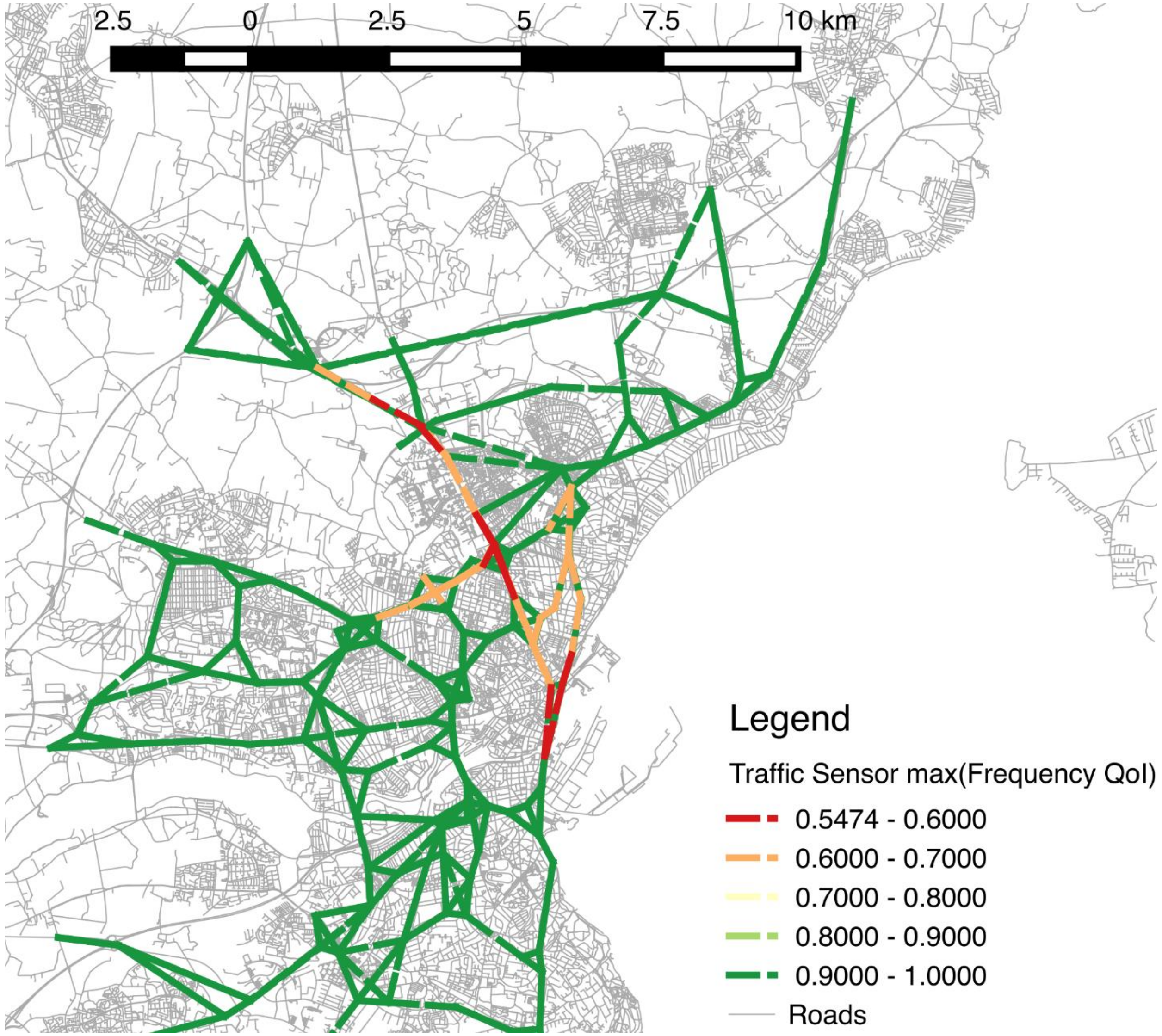
- Traffic Frequency



Composite Monitoring

- Main objective: prediction of errors and plausibility of events
- Main challenge: no available ground truth
- Composite Monitoring
  - Model based analysis of tempo-spatial related stream/sensor data
  - E.g. traffic sensor
    - A sensor reports slow traffic ➔ results in a detected traffic jam
    - Composite Monitoring validates event with the use of consecutive sensors on road
  - Usage of historic data (Atomic uses only current data of one sensor)
  - No real-time capabilities
  - Triggered by events or manual evaluations

Composite Monitoring

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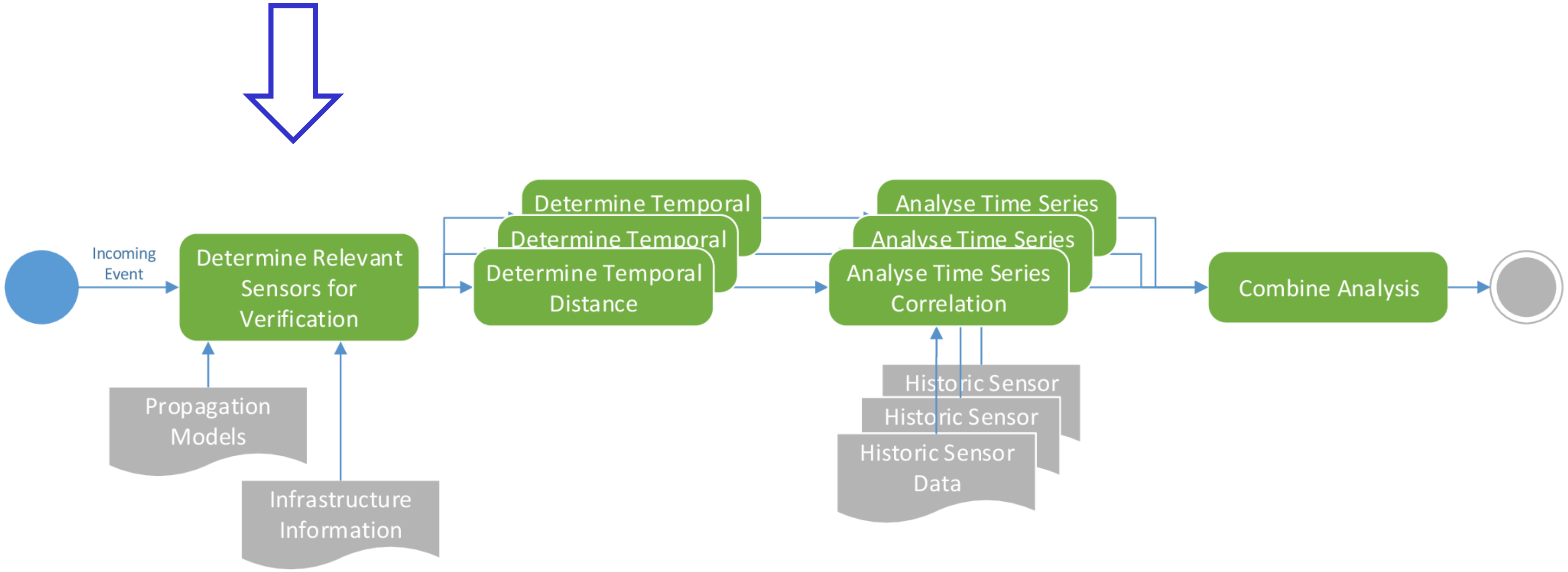
- Determine relevant sensors out of the set of all Streams (*s*)
  - Find spatially correlated streams by using a suitable distance model (*dm*), which describes the means of propagation of the event (air/street)



Composite Monitoring

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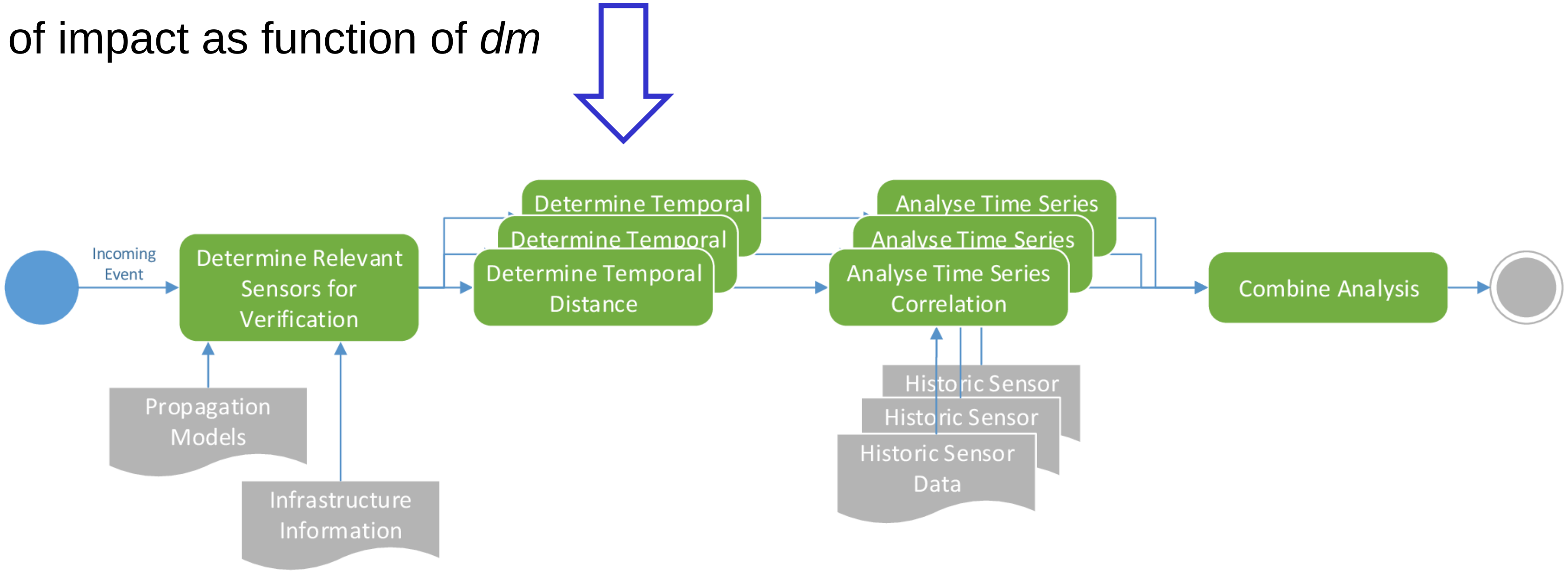
- Determine temporal distance by analysing the
  - Direction (*d*) of expansion
  - Propagation velocity (*v*)
  - Range (*r*) of impact as function of *dm*



Composite Monitoring

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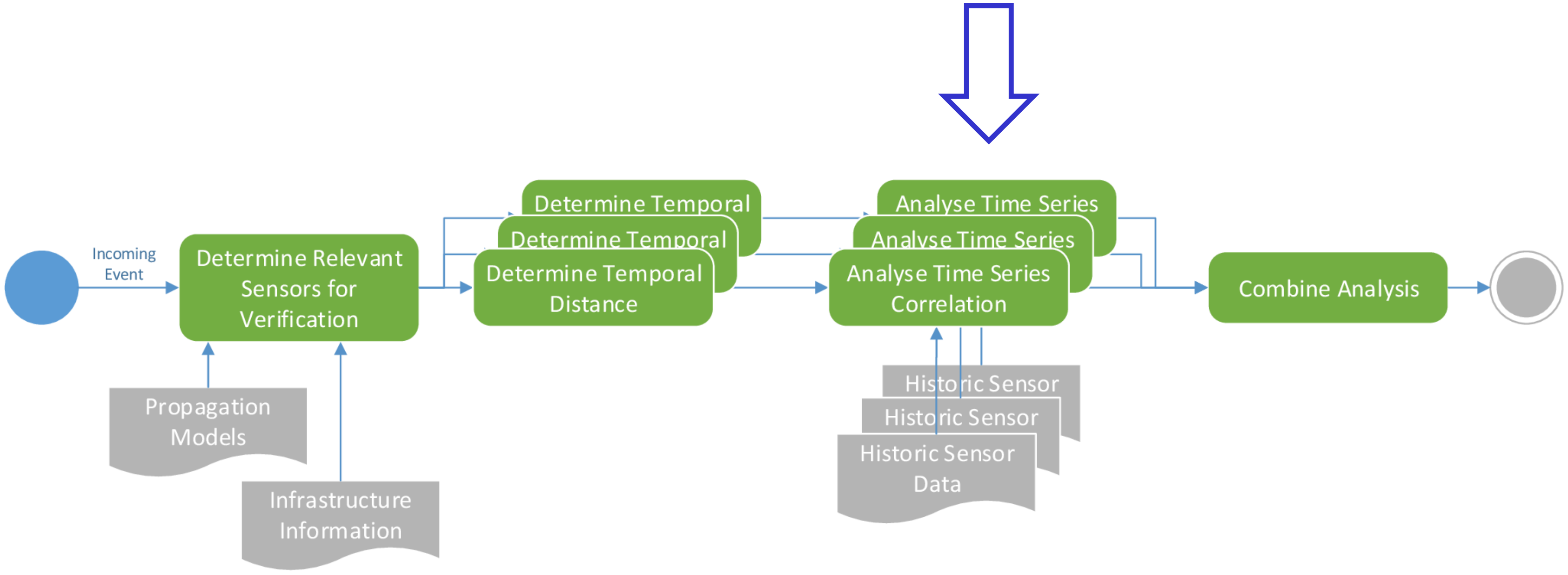
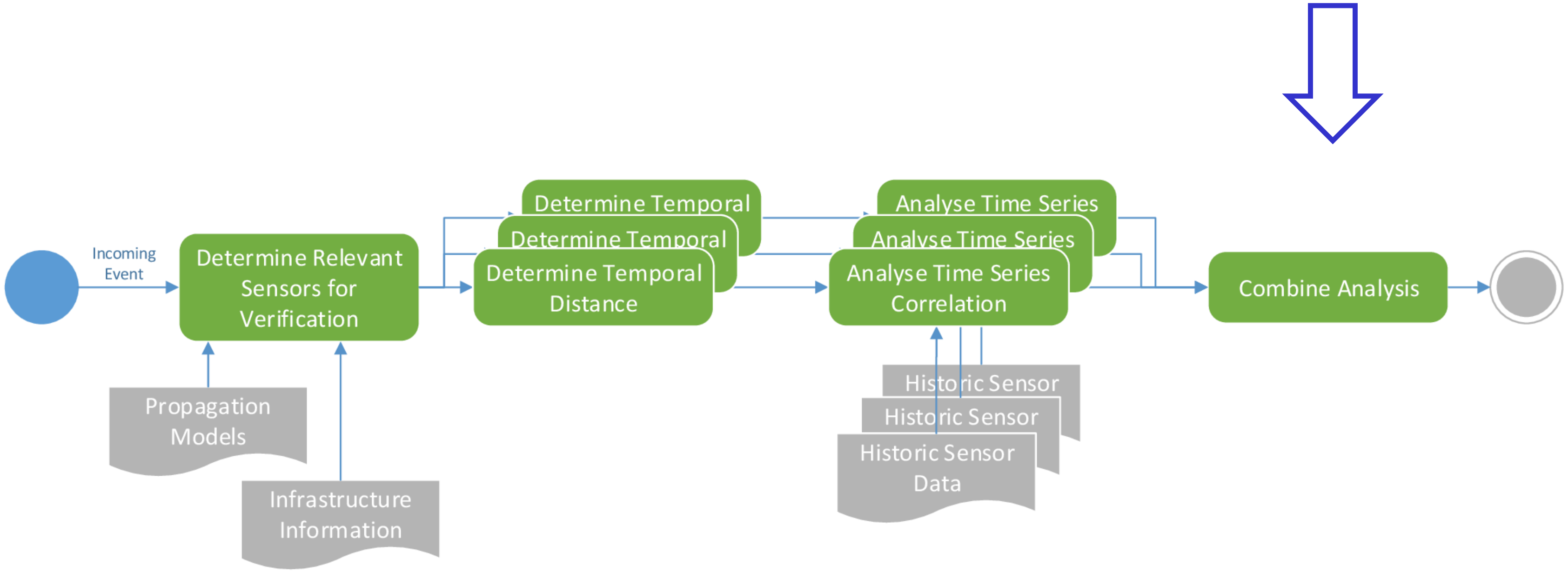
- Compute the correctness for each correlated stream by applying
  - *Vs* as the set of validator functions for e and each stream *s* ∈ *Se*
  - τ_s as set of temporal direction (is the change in s a result of *e*, or is it a cause for *e*?)



Composite Monitoring

- Combine all partial correctness values by using the:
  - Set of weights (*Ws*) for each stream *s* ∈ *Se*
  - A combination function (Σ), e.g. min, mean



- As a result, we get the combined correctness value (C_e)
  - $C_e = (S, dm, d, v, r, Vs, \tau_s, Ws, \Sigma)$.

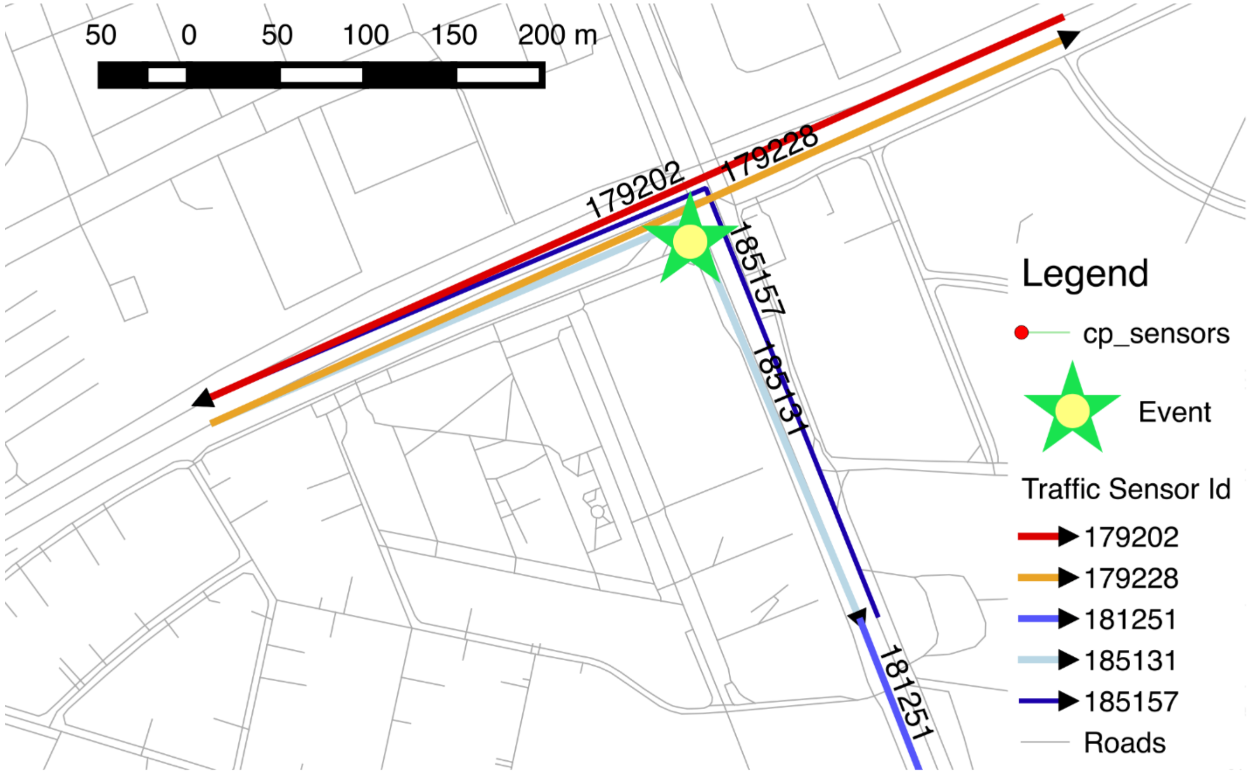
Composite Monitoring

- Example: Traffic Jam event created by Event Detection
  - Detected by sensors
  - Composite Monitoring is triggered by the event

```
sao:a26db0a4-20ca-4f4c-b553-a799200d58ca a
ec:TrafficJam ;
       ec:hasSource "SENSOR";
       sao:hasLevel "1"^^xsd:long;
       sao:hasLocation [ a geo:Instant;
              geo:lat "56.18244908701999"^^xsd:double;
              geo:lon "10.1972915214958"^^xsd:double
       ] ;
       sao:hasType ec:TransportationEvent ;
       tl:time "2016-02-12T13:57:07.001Z"^^xsd:dateTime
.
```

Composite Monitoring

- Example
  - Event location used to determine neighbouring relevant sensors
  - No temporal distance effect as event is in sensor measurement are
  - Analysis of time series for nearby sensors …



Composite Monitoring

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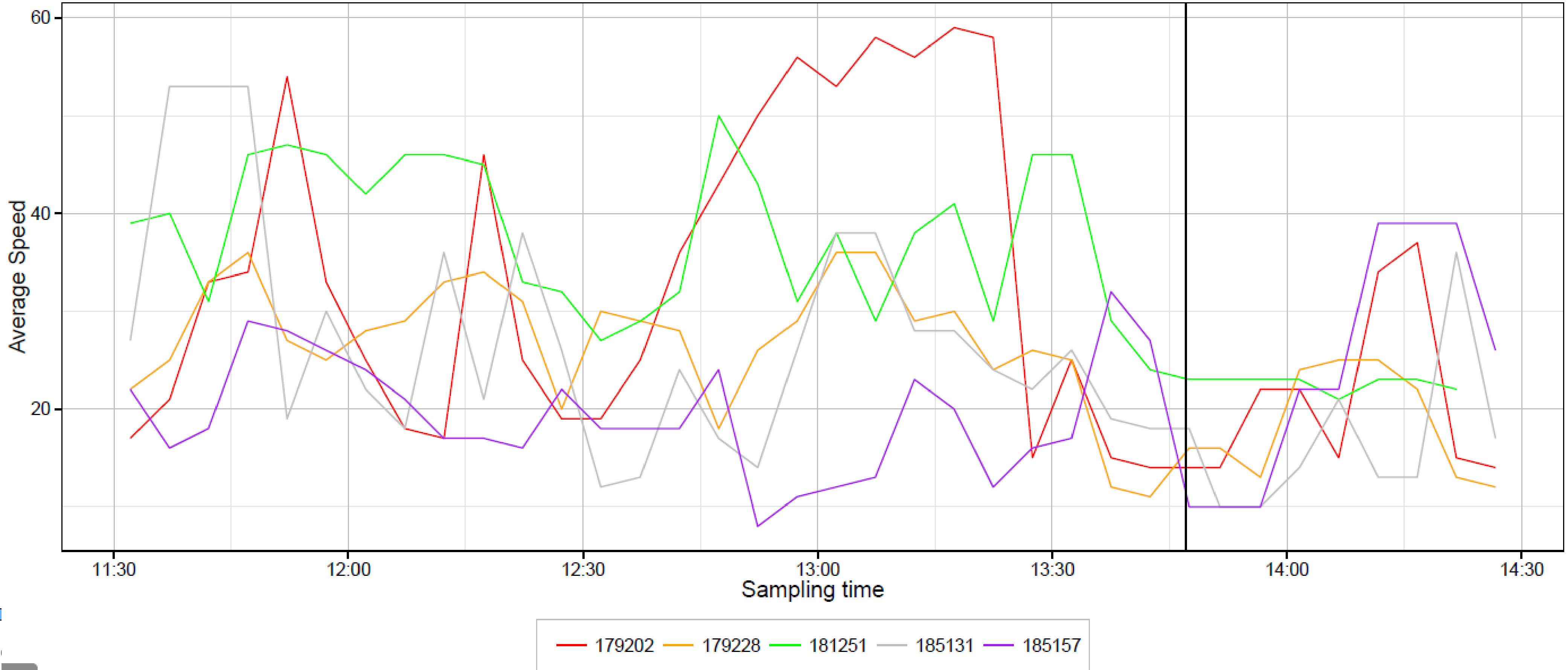
- Example
  - Time series analysation
  - Sensors 179202 and 179228 detecting slow traffic at event time
  - ➔ assumption that event is plausible



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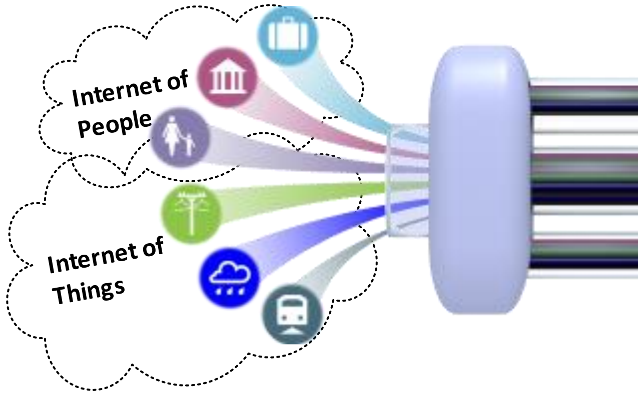
Conclusion

- Goal: Increased reliability of smart city applications
- Measures:
  - Testing during design-time
    - Determination of required QoI for an application
  - Monitoring during run-time, separated for scalability reasons
    - Atomic Monitoring
      - Basic QoI calculation, real-time capable
    - Composite Monitoring
      - Enhanced QoI check for events, complex by using spatiotemporal related streams



➔ CP-framework provides extensive methods to support reliable smart city applications

➔ Coping error-prone and incorrect data streams

➔ Future: Further investigation of Composite Monitoring, apply approach to different domains (e.g. environment, noise pollution)

End

Thank you for your attention!

Questions?

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