Decentralized Probabilistic World Modeling with Cooperative Sensing

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Arjan Peddemors

INCA Group
Telematica Instituut / Novay
Enschede, The Netherlands

Eiko Yoneki

Computer Laboratory
University of Cambridge
Cambridge, United Kingdom

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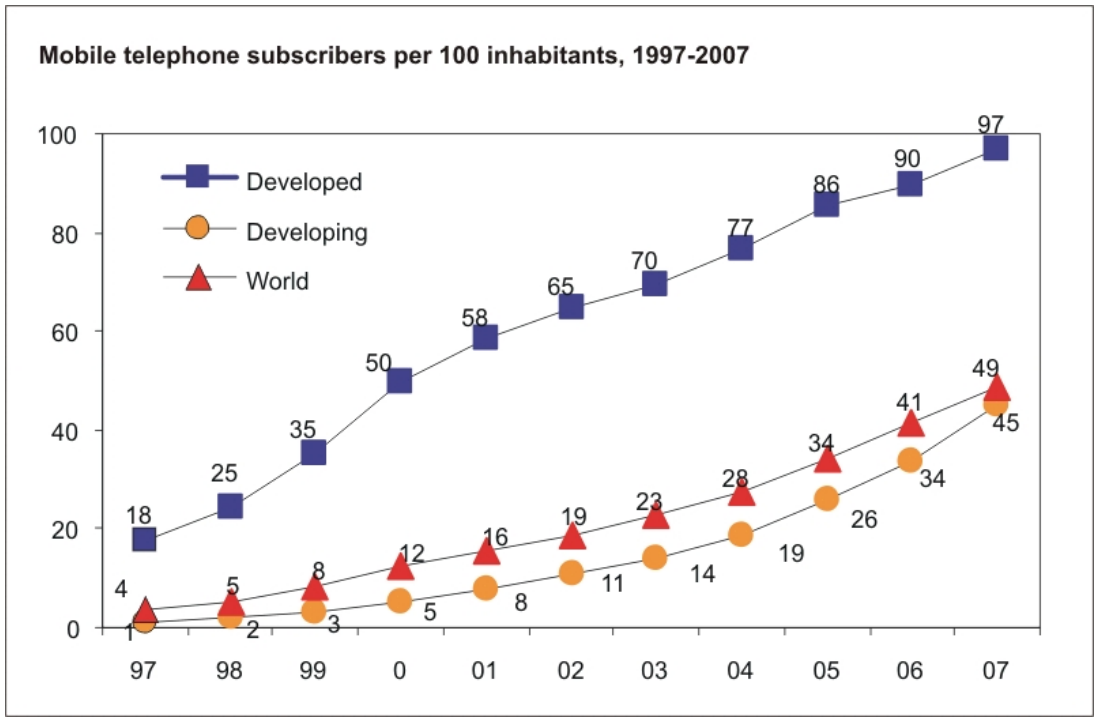
Mobile Phone Penetration

- Nov. 2007 (according to Informa)
  - 3.3 billion subscriptions
  - 6.6 billion world population



Source: ITU, http://www.itu.int/ITU-D/ict/statistics/ict/index.html, retrieved on 2008-09-02

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Interesting Times in the Mobile Device Market…

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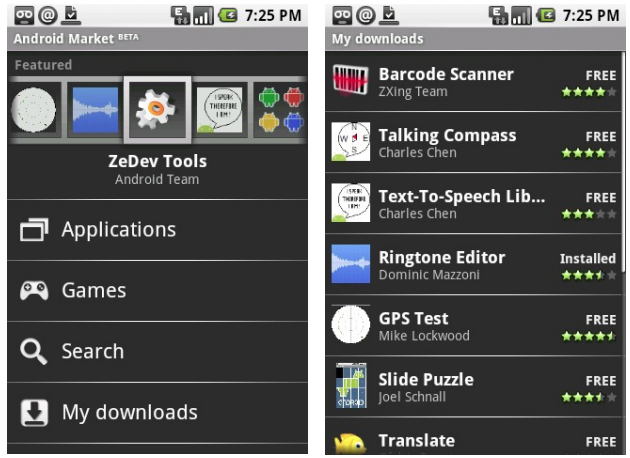
Mobile Phones – Open Platforms – Software getting more important

iPhone App Store

Android Market



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Mobile Phones – More and more sensing capabilities

- Wireless (network) interfaces
  - Cellular
  - 802.11
  - Bluetooth
  - RFID / NFC
- Geographical location (GPS)
- Acceleration
- Temperature
- Light
- Audio
- Video
- Touch

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Large scale sensing

- High number of mobile device owners (on world scale)
- Device close to its owner most of the time
- New powerful devices
- Take off of mobile internet
- Many sensors per device

Great opportunity to sense the world around us on a very large scale!

- Continuously
- Collectively
- Individually

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What if…

- …we store all information received from all the sensors on these personal mobile devices continuously?
- …we use this data to build a probabilistic world model – individually and collectively – to capture static features (objects) and dynamic features (behavior) of our environment?

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Then we can…

- Know at which location resources are available
  - E.g. where a person has access to WLAN networks while traveling
- Know where and when people are likely to meet
- Detect unusual situations
  - E.g. sense that a person is close to people he has not met before or only in another setting
  - E.g. sense that a road is blocked
- Predict upcoming events
- …

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Bottom-up Modeling

- Finding frequent patterns in the stream of data coming from the sensors that perceive our surrounding
  - General, not application specific
- Predefined structure
  - Incorporating primitives like roads, buildings, people, cars, artifacts, etc
  - Building and maintaining such a structure is a very large endeavor
  - Hard to identify unanticipated relationships between occurrences
- Bottom-up structure does not have these disadvantages

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Lots of data! Lots of processing!

- Example: CoSphere experiment (feb/march 2007)

```
==========================================================
summary
==========================================================
number of participants: 12

global number of unique used cells                    : 4120
global number of different in-range operators         : 18
global number of unique in-range 802.11 access points: 3787
global number of unique in-range 802.11 networks      : 1725
global number of unique in-range bluetooth nodes      : 6679
```

- Much more data expected from other types of sensors

CoSphere trial data: http://cosphere.telin.nl/trial/, retrieved on 2008-09-02

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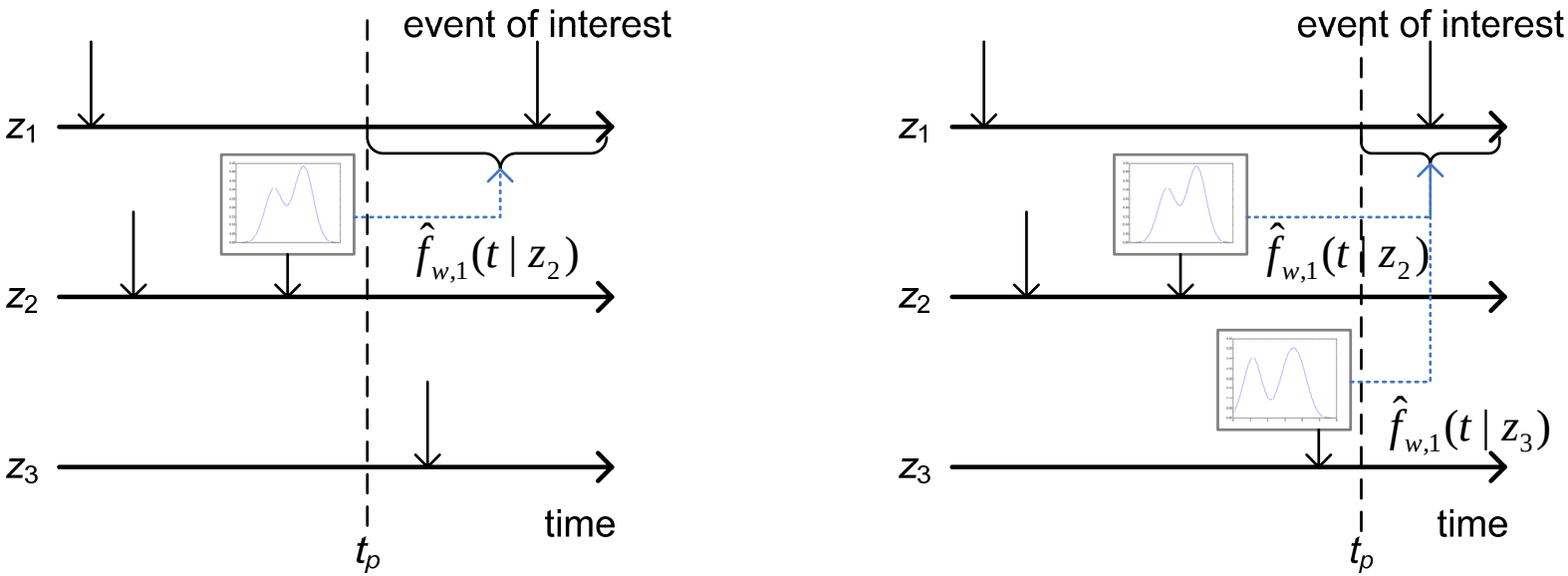
Example: prediction of future network visibility (mobile device perspective)



- Forecasting visibility event based on already seen (other) visibility events
- These other events act as ‘predictors’
- Use the best predictor when multiple are available

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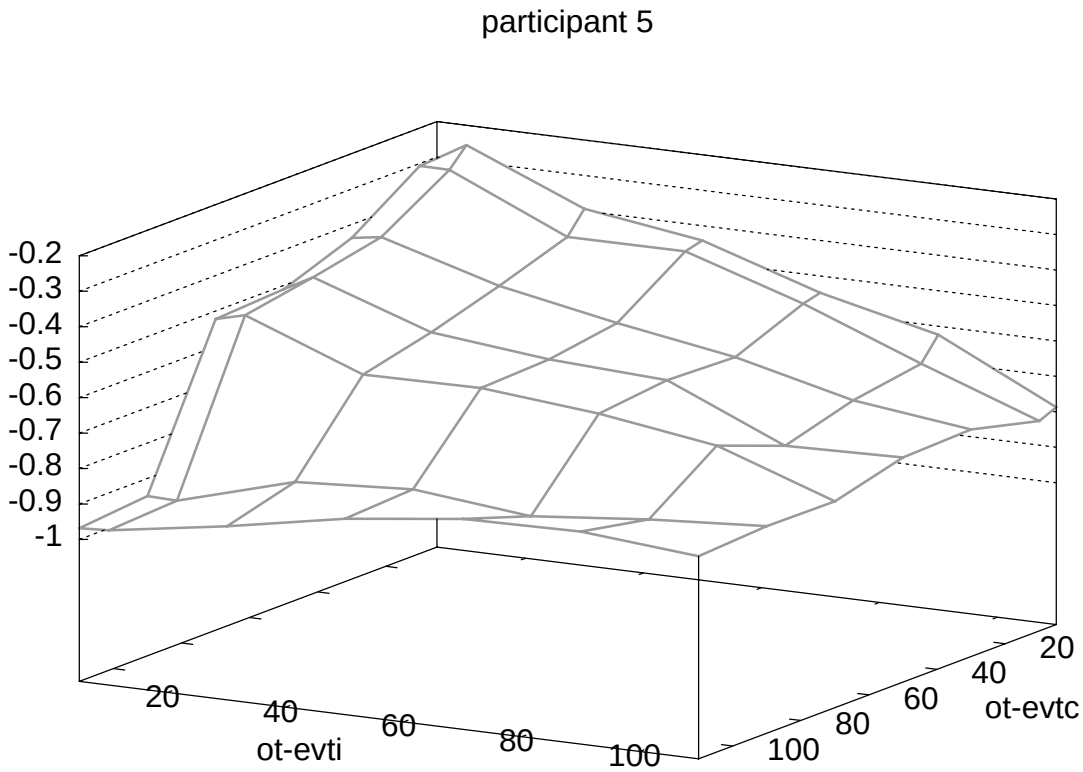
Example: prediction of future network visibility (mobile device perspective)

- Does it help to take the visibility of other infrequently seen networks into account? YES



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Example: prediction of future network visibility (mobile device perspective)

- Does it help to use information from one network interface (one sensor) to predict events on another network interface (another sensor)? YES, but…
  - The case for almost all participants
  - ‘Inter-tech’ prediction contributes more than ‘intra-tech’ prediction
- What do we learn from this?
  - Use as much sensor data a possible
  - Sensor data fusion works

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Probabilistic World Modeling
Example: compositional hierarchies

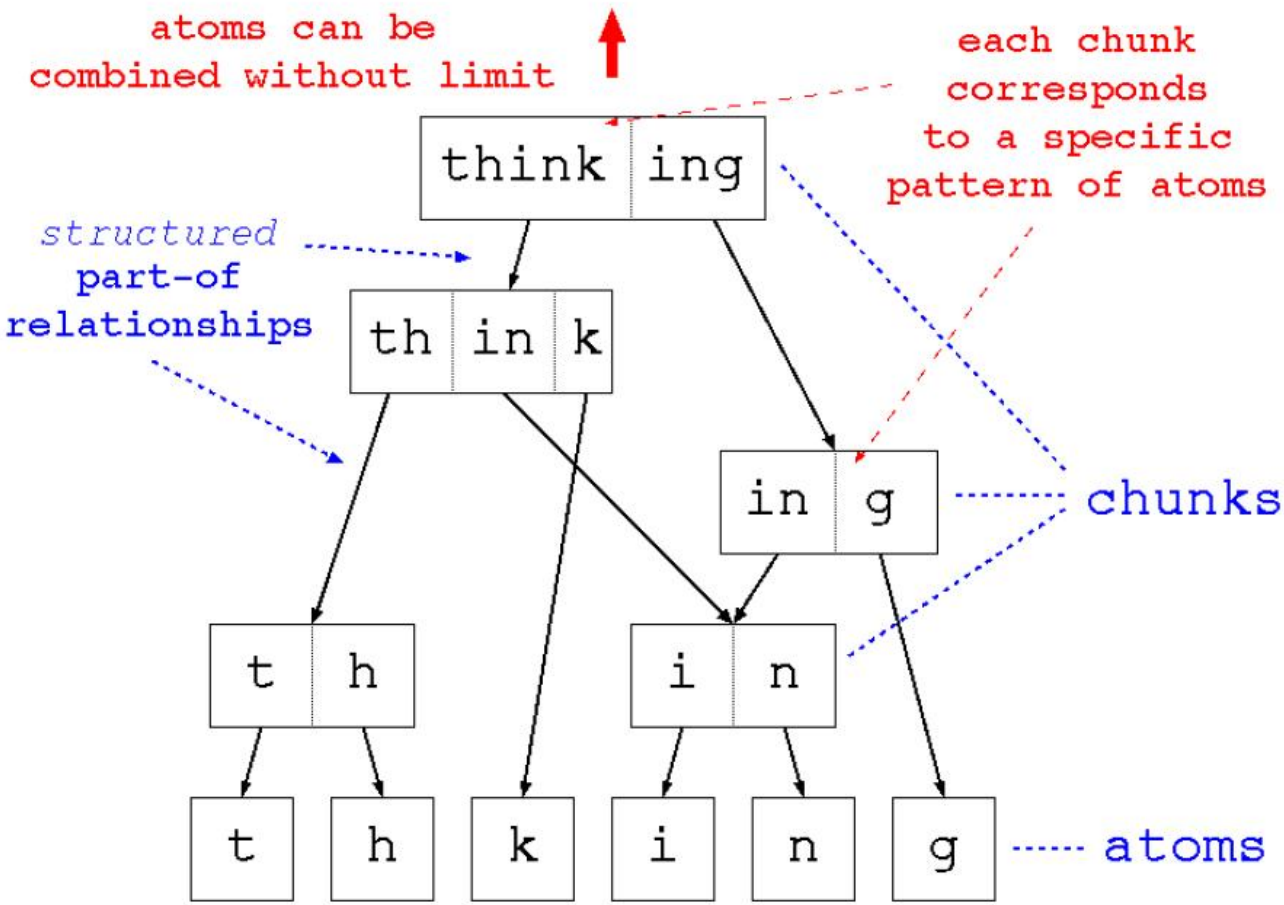

Figure taken from Karl Pfleger's PhD defense presentation,
http://www.ksl.stanford.edu/people/kpfleger/ , retrieved on 2008-09-02

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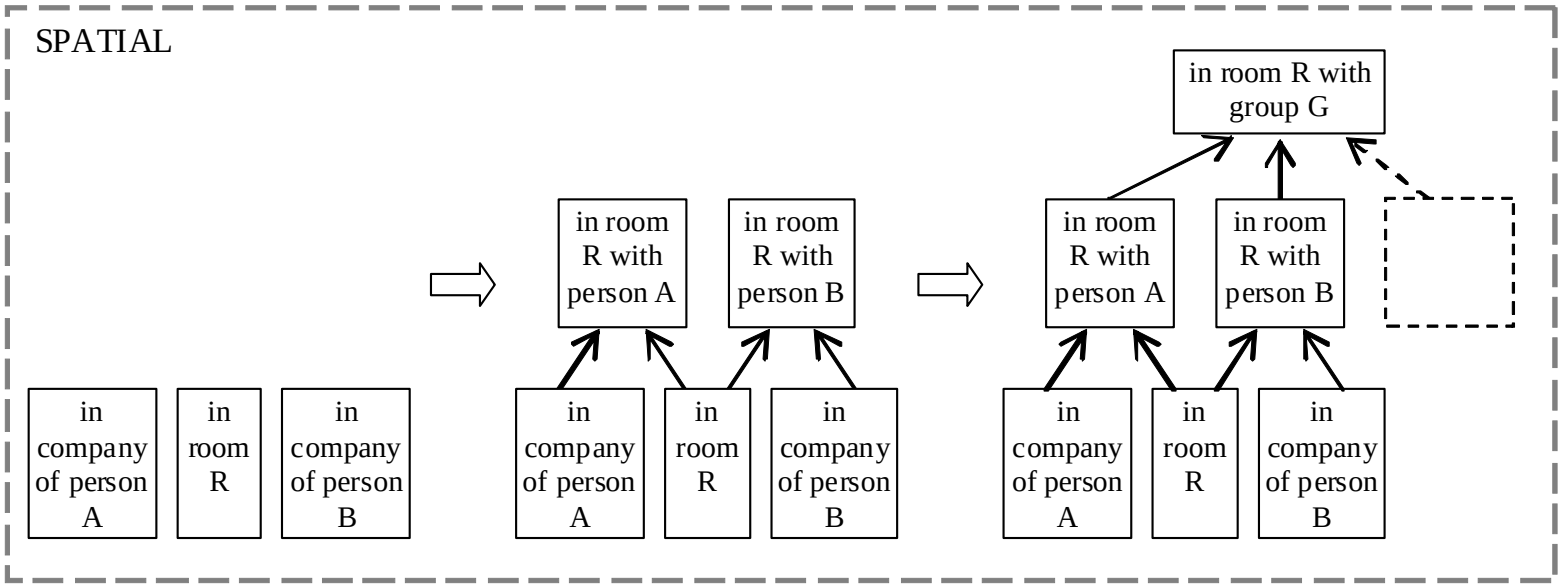
Probabilistic World Modeling
Example: compositional hierarchies



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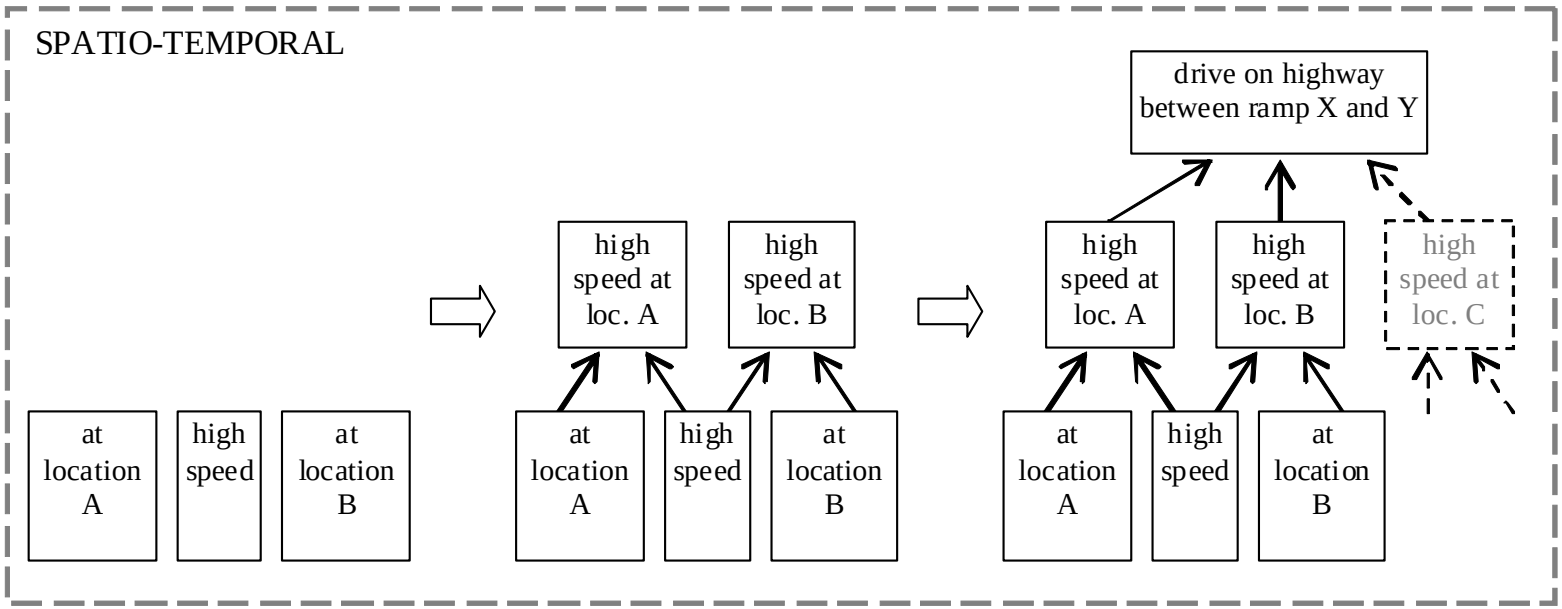
Probabilistic World Modeling
Example: compositional hierarchies



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Collective Effort

- By sharing the models built on individual nodes (mobile devices), we may
  - Increase the overall model accuracy
  - Use the observations of others in environments unknown to individual nodes

- We propose to take a decentralized P2P approach
  - No centralized role that may interfere with privacy
  - Exchange of model data with those that are most relevant
  - Opportunistic data exchange, when nodes (peers) are near, using short range wireless networks

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Discussion (many open issues)

- Semantic ‘gap’: how can we bridge the gap between the probabilistic model and application logic
- Difference in sensor quality and calibration may interfere with collective model building
- Difference in hierarchy building between individual nodes may make model data exchange difficult
- Uncertain whether a generic model is capable of supporting a wide range of applications

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Discussion (many open issues)

- Temporal patterns evolve at widely varying rates
- Computing resources
- Opportunistic spread of model data
- Privacy

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Summary

- Personal mobile device
  - Exciting platform to do large scale sensing and modeling of the world around us
- Probabilistic world modeling
  - Open and promising field of research
  - Bottom-up , no need for predefined structure
  - Helping to find collective and individual patterns of behavior
- Opportunistic data exchange
  - P2P based
- This is a truly multidisciplinary effort!

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