Incentive Schemes for Community Sensing

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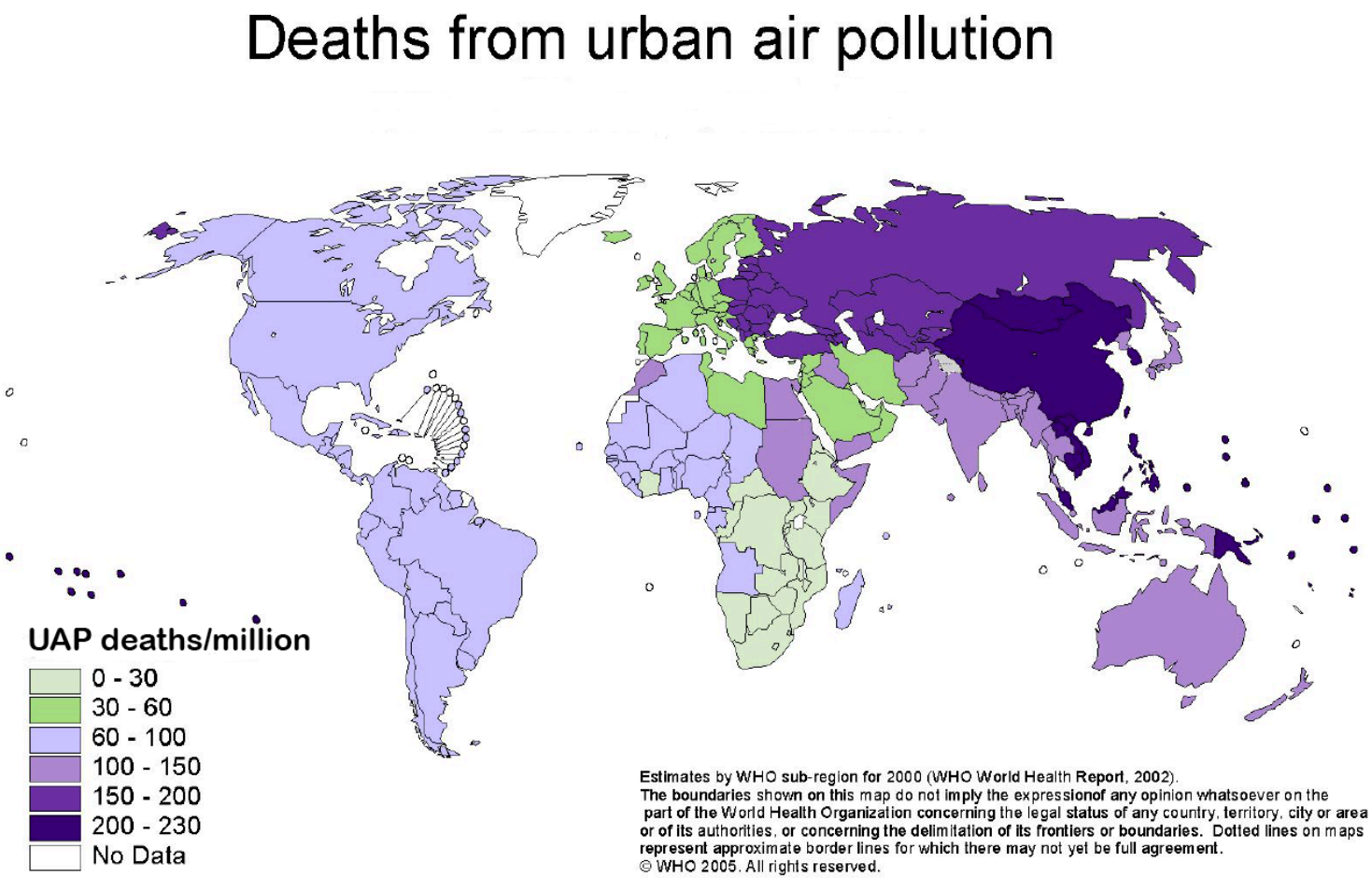
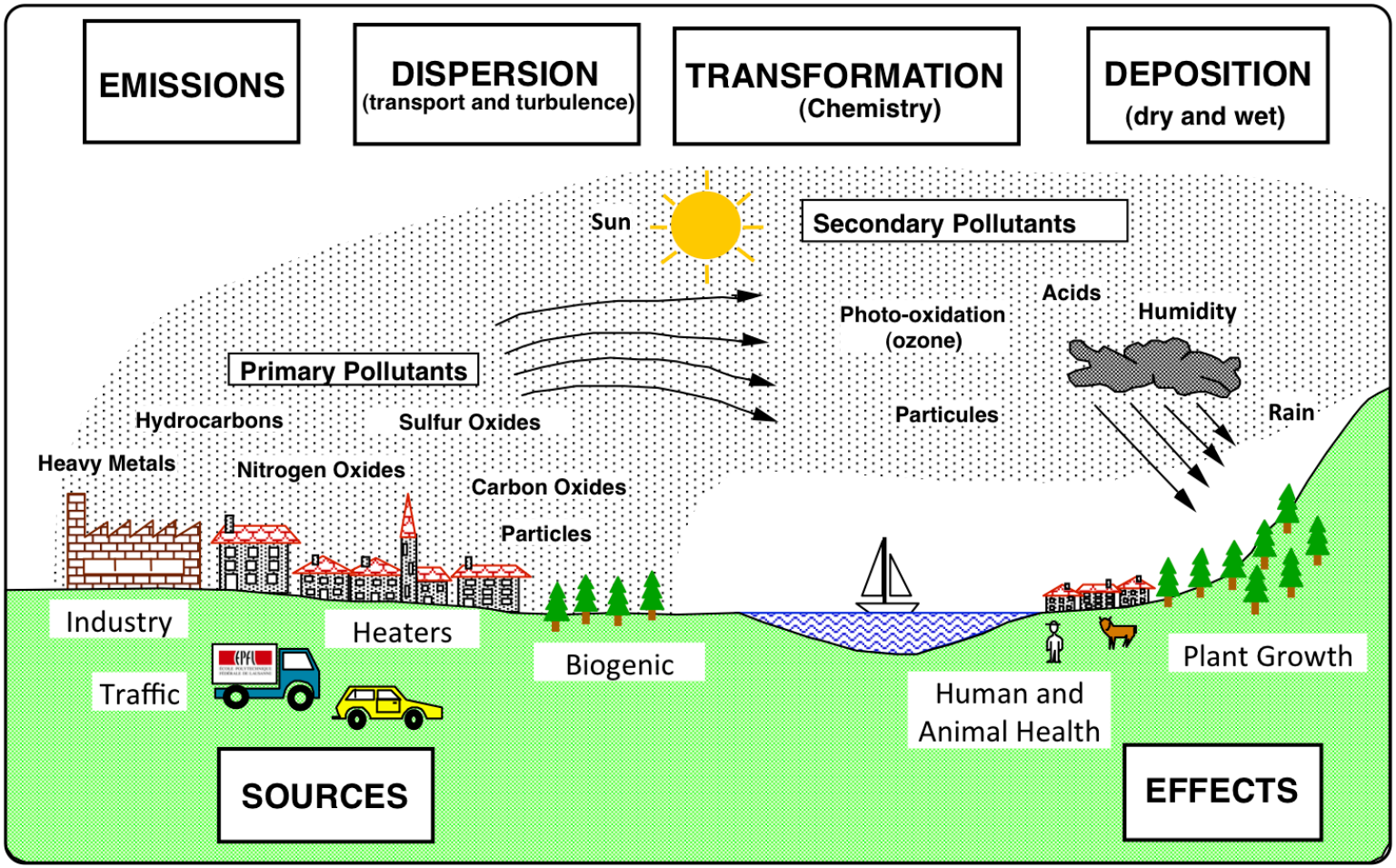
Why Sensing

- For Truth
  - Collect evidence of important environmental phenomena that are not easily observable / quantifiable.
    - How hot is it out there?
    - How polluted are the air and the waterways?
    - How much emissions were created by X corporation?
  - Evidence before policy.

Health Impact of Air Pollution

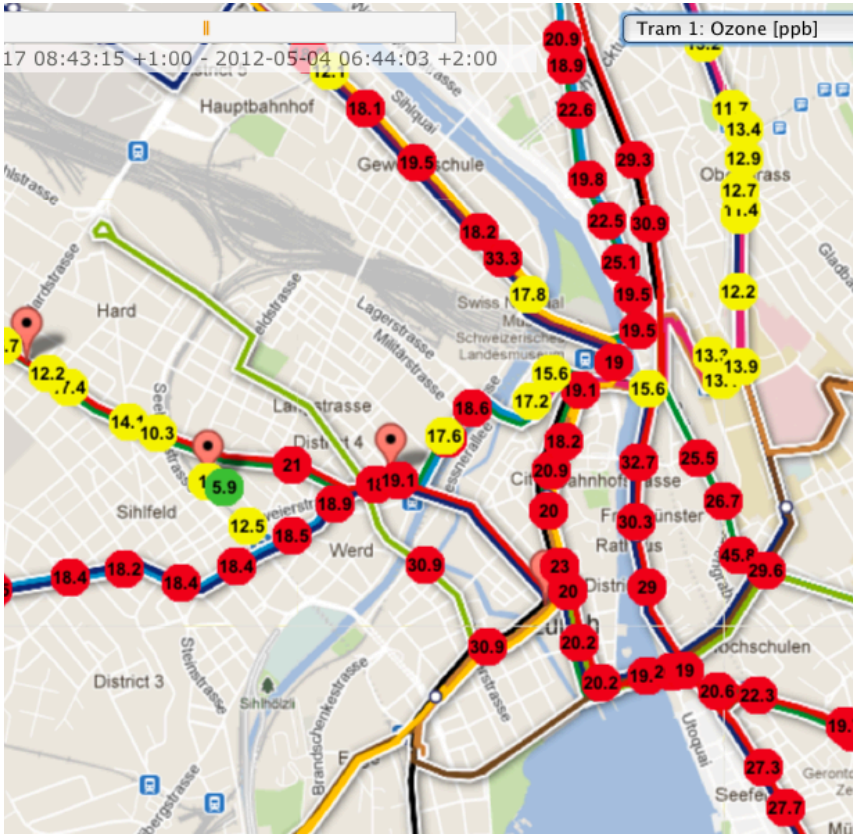


Story of Air Pollution



Why Mass-Sensing

- Air pollution varies in space and time
  - A single station is not sufficient for analyzing exposure
  - A mass deployment is required for detailed picture
- Results may be used for:
  - Everyday decisions
  - Health warnings
  - Exposure studies
  - Emission monitoring



Planned vs. Community Sensing

Centrally Allocated, Top Down

Grass-root participatory, Bottom Up

Community Sensing

- A community of agents (sensors) making measurements and report values to a center

OpenSense

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Community Sensing

- The center aggregates agent measurements, integrate them to an model, and publishes a pollution map as a public service

Community Sensing Challenges

- Supply:
  - Each agent (sensor) needs to be compensated for their investment and maintenance
    - Accuracy may degrade without adequate maintenance
- Demand:
  - The center needs the agents to continuously report reliable measurements
  - The center has no direct control. It can't tell the agents:
    - Where to go
    - Report what they really think or measured

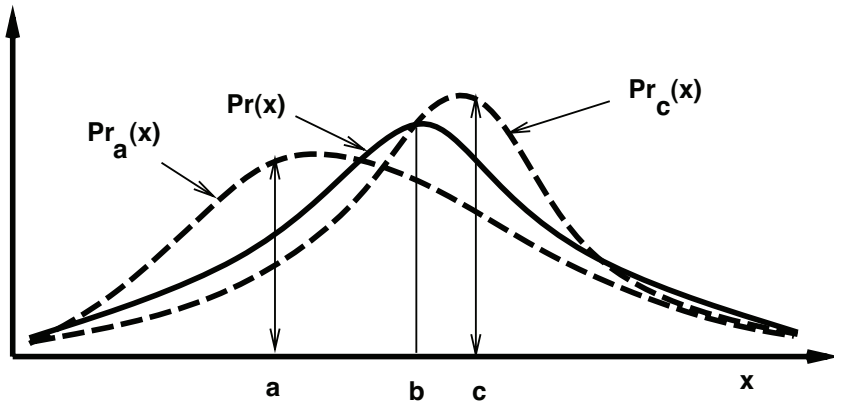
Incentive Schemes

- Needed:
  - An incentive-compatible mechanism that facilitates good reporting policy:
    - Continuous reporting of good measurements.
  - Rewards:
    - Monetary: compensate sensors for providing measurements
    - Reputation: exclude sensors that provide wrong measurements (maliciously or otherwise)

A Game Theoretic Setting

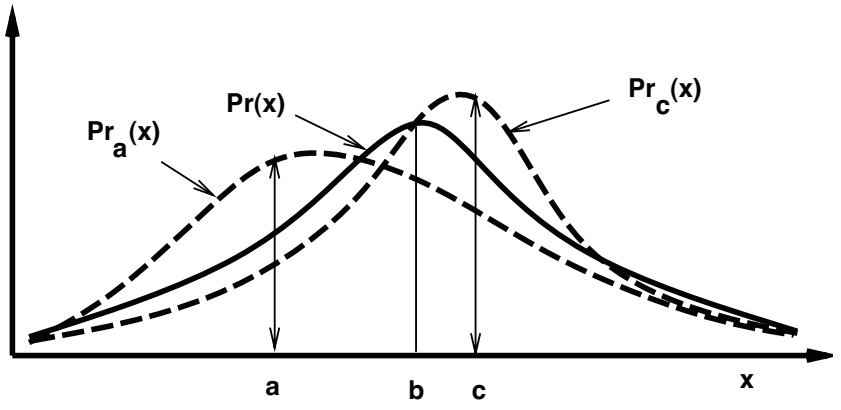
At a given time and location:

- the center publishes statistics for a public prior probability R(v) that the pollution level is v.
- Agents adopt R(v) as their prior expectation Pr(v).
- After observing measurement o, the agent has an updated private posterior $Pr_o(v)$.



First Mechanism

- Mechanism with Proper Scoring Rules [Savage, 1971; Papakonstantinou, Rogers, Gerding and Jennings 2011]
  - Agent report the posterior distribution Pr_o to the center
  - The center evaluates it with the observed the ground truth g and computes the actual reward:
    - $P(Pr_o, g) = a + b * S(Pr_o, g)$
- Incentive Compatible: highest expected payoff comes from reporting true private beliefs.



Example with Scoring Rule

- Common Prior: L=0.1, M=0.5, H=0.4
- Quadratic Scoring Rule:

$$pay(\bar{x}, p) = a + b\left(2p(\bar{x}) - \sum_{v} p(v)^2\right)$$

- Agent Posterior: L=0.1, M=0.8, H=0.1
- Payment for ground truth=M:
  - $a + b * (2*0.8 - (0.1^2+0.8^2+0.1^2))$
- Expected Payment
  - $a + b * (0.1*(2*0.1 - (0.1^2+0.8^2+0.1^2))$
    $+ 0.8*(2*0.8 - (0.1^2+0.8^2+0.1^2))$
    $+ 0.1*(2*0.1 - (0.1^2+0.8^2+0.1^2)))$

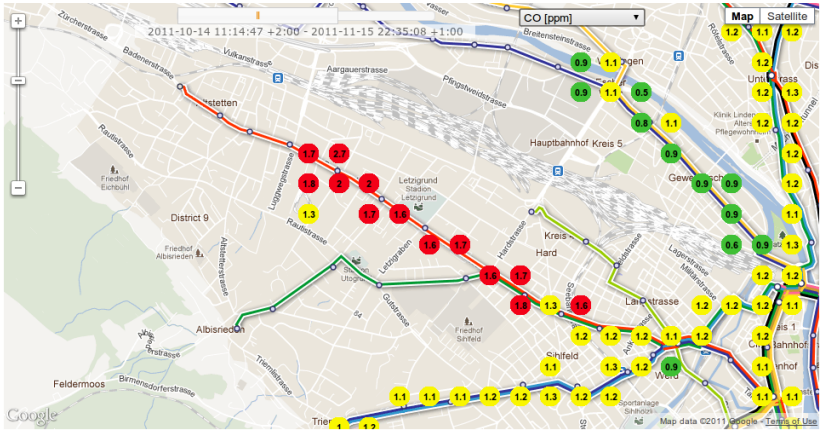
  $= a + 0.66 * b$
- For non-truthful report L=0.1, M=0.3, H=0.6, Expected Payment = a + 0.15 * b

Problems with Applying Scoring Rules

- Ground truth is required to evaluate the agent's report
  - Sensors measuring at exactly the same place and the same time.
- Agent would require to submit its full posterior distribution
  - Problematic if the posterior cannot be nicely described (needed likelihood for every possible value)

Overcoming Lack of Ground Truth

- Solution: based on peer prediction [Miller, 2005]
  - Substitute ground truth with peer reports
  - Truthful reporting becomes a Nash-equilibrium
    - If all others report truthfully, best strategy is to report truthfully

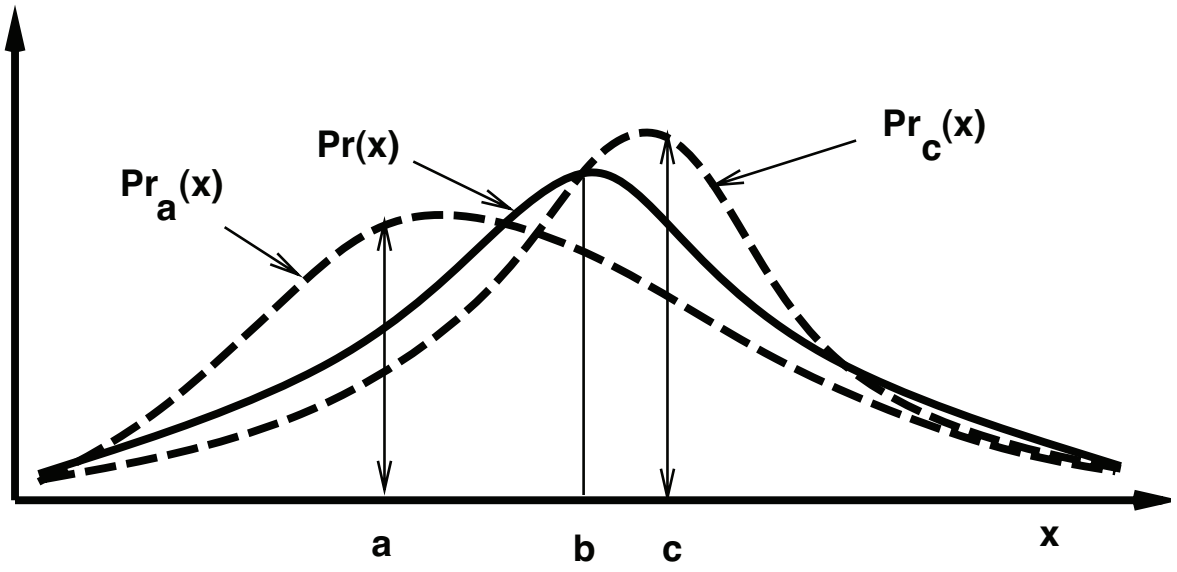


Evaluating Sensing Reports

- Poll Mechanism: substitute ground truth with a stochastically relevant signal
  - An integrated environmental model that computes an unbiased estimate from other agents' reports and physical knowledge
  - Agents make inference based on their belief of the model outcome
  - Assumption: when there are sufficient reports, the model output is an unbiased estimator of the ground truth.

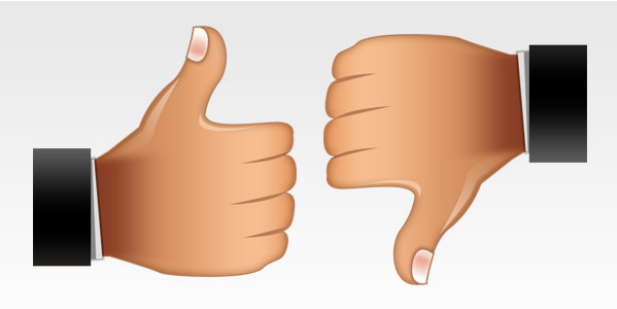
A New Incentive Scheme

- Pr = Agent belief of the model estimation
- Assumption: the agent believes in his measurement fitting the model:
  - $Pr_o(o) / Pr(o) > Pr_o(o') / Pr(o')$ for all o' != o.



A New Incentive Scheme

- Poll Mechanism
  - Once report s is submitted, the center computes an unbiased estimate m, and reward the agent with payment function according to the public prior R.
    P = a + b * T(s,m,R):
    - T(s,m,R) = 1 / R(s) if s = m;
    - T(s,m,R) = 0 otherwise.



Why it works

- Suppose agent measures v:
  - Expect payment for reporting v:

    = a + b * $Pr_o(v) / R(v)$
  - By assumption:
    - $Pr_o(o) / Pr(o) > Pr_o(v) / Pr(v)$ for all v != o
  - Truthful reporting has the highest expected payoff.
  - No other assumption about the posterior is required.

Example with Poll Mechanism

- Common Prior: L=0.1, M=0.5, H=0.4
- Agent Posterior: L=0.1, M=0.8, H=0.1
- Payment Function:
  - P(s,m,R) = a + b / R(s) if s=m
    = a otherwise.
- Expected Payment:
  - L: a + b * 0.1 / 0.1 = a + b
  - M: a + b * 0.8 / 0.5 = a + 1.6*b
  - H: a + b * 0.1 / 0.4 = a + 0.25*b

Summary

- Community sensing needs good incentive schemes
- A practical, incentive compatible mechanism for community sensing
- Further work is needed to handle collusion, handling large external incentives, etc.