Computing Challenges in Intelligent Transportation Systems

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Relatively small impact of IT (not electronics) on travel experience

- Routing
- Real-time public transport (e.g. bus-tracker)
- Autonomous driving
- Fleet Management Software
- Car navigation systems (payment for info)

Why?

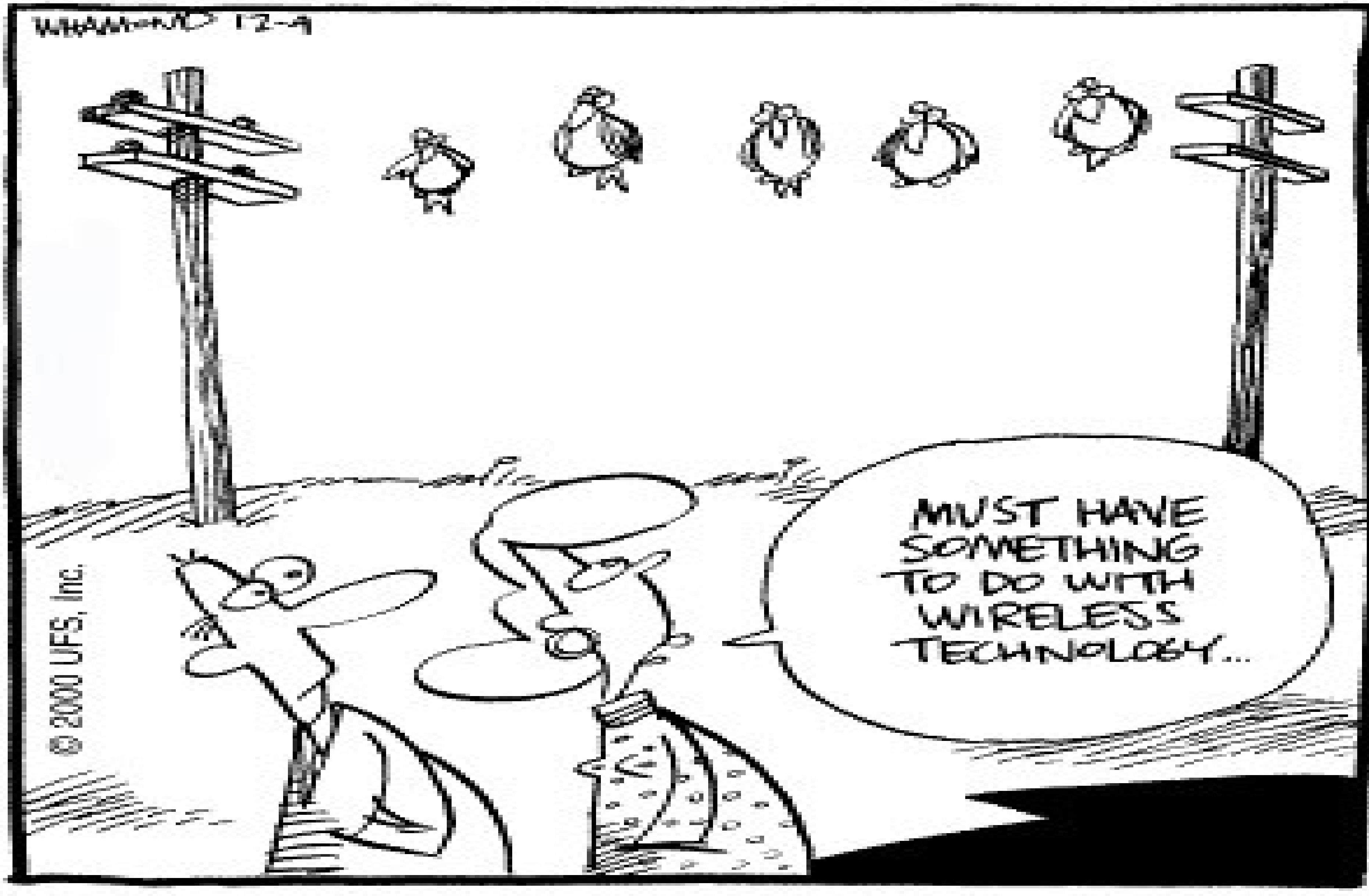
- Distributed/mobile system of unprecedented scale
- Incentive mechanisms / business models
- Conservative community

Intellidrive- A federal initiative
http://www.intellidriveusa.org/

A V2V, V2I, V2D communication infrastructure that will provide information about all roads all the time

Using Wireless technology

Gaining popularity in animal kingdom



From DOT IntelliDrive presentations

Work zone notification

Collision avoidance

IntelliDrive Vision

- Take advantage of advances in
  - Wireless communication (communicate)
  - Mobile/static Sensor technologies (integrate)
  - Geospatial-temporal information management (analyze)

- To address transportation problems related to
  - Congestion
  - Safety
  - Energy
  - Environment
  - Sustainability

Delay and accidents cost $365B/yr in US
Problem getting worse: Between 1990 and 2007,
Vehicle-Miles-Travel grew 41%
Expected to grow 60% by 2050
to 4,834B miles/yr

IntelliDrive Approach

– Convene a “Coalition” of stakeholders—
  - Auto manufacturers,
  - State/local transportation authorities,
  - University Transportation Centers
  - USDOT—

– to work through issues:
  - technical,
  - policy,
  - business models,

Safety applications: situational awareness

- make a driver aware of unforeseen vehicles, road conditions, and hazards:
  - Vehicle in front has a malfunctioning brake light
  - Vehicle on crossroad is about to run a red light
  - Patch of ice at milepost 305
  - Vehicle 100 meters ahead has suddenly stopped
    (EEBL emergency electronic brake light)

Efficiency/convenience/mobility applications

- on-route traffic and weather conditions,
  - What is the average speed a mile ahead of me?
  - Is the upcoming pavement wet there?
  - Are wipers/fog-lights on there?
  - Are there any accidents ahead?
- Resource availability
  - gas station location and prices,
  - parking availability and prices,
  - What taxi cabs are there around me?
  - Does the next Route 7 bus have a bike rack?
- Multimodal trip planning and execution.
  - Optimization by time, distance, cost

Environmental/Energy applications

- Multimodal navigation for optimal
  - Pollution generation/exposure
  - Greenhouse Gas generation
  - Energy consumption
- Subject to
  - Facilities visit
    - Recharge for electric cars
    - Florist, supermarket, pharmacy
  - Time, distance, cost < x

History

- Evolution from
  - Autonomous driving (darpa challenge)
  - Automated Highway Systems (San Diego 1997 demo)
  - VisLab: 13,000Km without driver: on July 20, 2010 2 electric vehicles will depart from Italy to China, arriving after a 3 months without driver; powered by solar energy www.IntercontinentalChallenge.eu
- ITS intermediate step
- Robotic chauffeur still ultimate goal
- But many benefits can be achieved on way

Lesson from background

- Hundreds of currently existing/envisioned applications

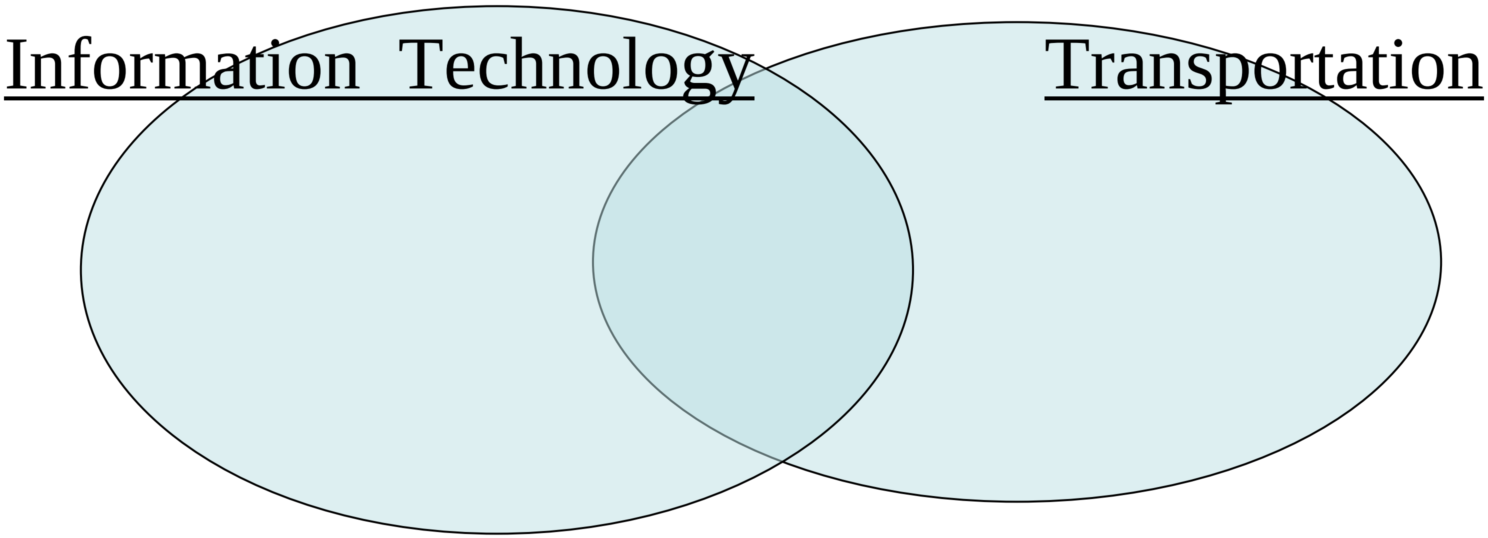
- Many others when business/technological infrastructure established

- infrastructure + entrepreneurship

  =>

  transformative cultural change = new companies products, services, a la internet 1990’s

IGERT Ph.D. program in Computational Transportation Science



- Funded by the National Science Foundation ($3M+)
- Trains about 20 Scientists
- Colleges: engineering, business, urban planning

IT Research Challenges (will discuss these)

- Develop an IntelliDrive platform for building applications
  - A software architecture
  - Interfaces
  - Tools
  - Services

  that enables easy application-development
- Mixed environments: information processing in vehicular/P2P/cloud networks.

Other IT research challenges (will not discuss these)

- Data mining: Abstraction of concepts from spatio-temporal data (streams)
  - transportation mode inference based on:
    - Gps receiver
    - Sound detector
    - accelerometer
  - Sensor-stream fusion into a visual model of accident
  - Road-weather (Precipitation, visibility, traction) based on wipers/lights/traction sensors of probe cars

    information search,
    stream management,
    Information integration (weather-centers, forecasts, fixed sensors)
- Algorithmic game-theory: Optimal routes when everyone has up-to-minute traffic info

- Social networks, crowd-sourcing, persuasive technologies
  - Incentives

Optimization algorithms (relevant, ongoing)

- Multi-objective optimization:
    - Pollution generation
    - Energy consumption
    - Time,
  - Subject to constraints
    - Facilities encounter
    - Cost < $4

HCI / AI / Privacy / Security (broader scope, will not discuss)

- Speech recognition
- Natural language understanding
- Machine vision for scene understanding
- Privacy / Security of Information Systems

Outline for rest of talk

- IntelliDrive Platform Components for
  - Trajectory Management
  - Evaluation: Electronic Emergency Brake-Light

  Based on our work

- Mixed environments: information in vehicular/P2P/cloud networks.

Why Platform?

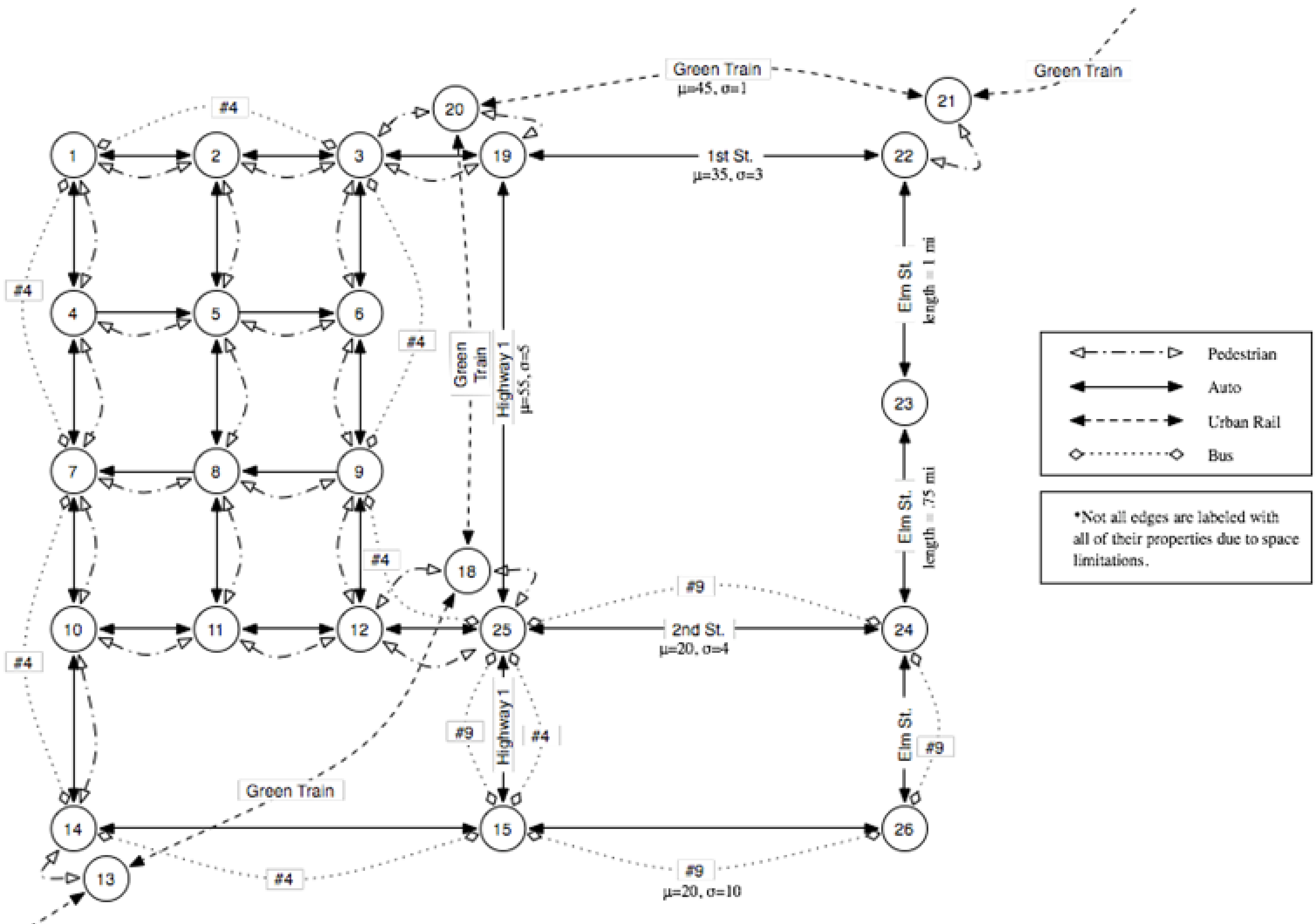
- Does not currently exist
- Without it: simple logic of application may become horrendeous software development task
- Same state of affairs led to DBMS introduction

DBMS-style trajectory management

- Application of DBMS to Transportation is not straightforward
  - Data model more complex than relational
  - Query language defficient
- Keep/translate benefits of DBMS
  - Common data model
  - Declarative query language with
    - spatial,
    - temporal,
    - uncertainty

  capabilities (Syntax + Semantics + Processing Algs.)

Data Model for Multimodal Transit (more complex than relational)



Example queries

- Find a multimodal route that will get me home by 7pm with 90% certainty.

- Find a route that will get me home by 7pm with 90% certainty, and

  lets me stop at a grocery store for 30 minutes

General Query Syntax

```
SELECT *
FROM ALL_TRIPS(origin, destination)
WHERE

<WITH STOP VERTICES> (florist, grocery)

<WITH MODES>         (Bus, boat)

<WITH CERTAINTY>     (0.8)

<OPTIMIZE>)  (time, distance, cost, #transfers),…)
```

Example Query

With a certainty greater than or equal to .75, find a trip home from work that uses public transportation and visits a pharmacy and then a florist (spending at least 10 minutes at each) and has minimum number of transfers

```
SELECT *
FROM ALL_TRIPS(work, home) AS t
WITH STOP_VERTICES v1, v2
WITH CERTAINTY .75
WHERE "pharmacy" IN v1.facilities
AND "florist" IN v2.facilities
AND DURATION(v1) > 10min
AND DURATION(v2) > 10min
AND MODES(t)contained-in {pedestrian, rail, bus}
MINIMIZE number-of-transfers
```

Query Semantics

From the set of trips that satisfy:

- the non-temporal constraints, and
- the temporal constraints with the required certainty (remember probabilistic travel times)

Select the optimal (according to single criteria)

Semantics

```
Select *
From All_Trips (work, home) as t
WITH STOP-VERTICES v1
WHERE pharmacy in v1.facilities, and
            modes(t) contained-in {train, bus}, and
            begin(t) > 8pm, and
            arrive(t) <10pm, and
            duration(v1) > 10mins
WITH CERTAINTY   0.9
MINIMIZE NUMBER-OF-TRANSFERS
```

For each trip from work to home create a mapping from v1 to vertices of t:

```
t1….      (t1,map1)      map1: v1 -> UnionStation
t1….      (t1,map2)      map2: v1 -> CentralStation
t2….      (t2,map1)      map1:  …..
.
.
```

For each (t_i, map_j) evaluate WHERE condition and if satisfied with CERTAINTY > 0.9 put pair in RESULT.

From RESULT return the pair that MINIMIZES the number of transfers.

Evaluation of WHERE condition W on (t_i,map_j)

- Evaluate non-temporal conditions and if W = ‘true’ or ‘false’ , then done.
- Otherwise split trip into legs: L1, v1, L2
- L1 has departure y_1 and duration z_1
- L2 has departure y_2 and duration z_2
- y_1>8pm, y_2+z_2<10pm, $y_2-y_1-z_1$>10mins defines a region S in R^4.
- Assume that we know the joint density function $f(y_1,z_1,y_2,z_2)$.
- Then we compute the probability of W as the integral
  $\int_S f(y_1,z_1,y_2,z_2)dy_1dz_1dy_2dz_2$

Plug-and-play Query Processing

- Based on a framework
  – Algorithms are chosen based on the structure of the query

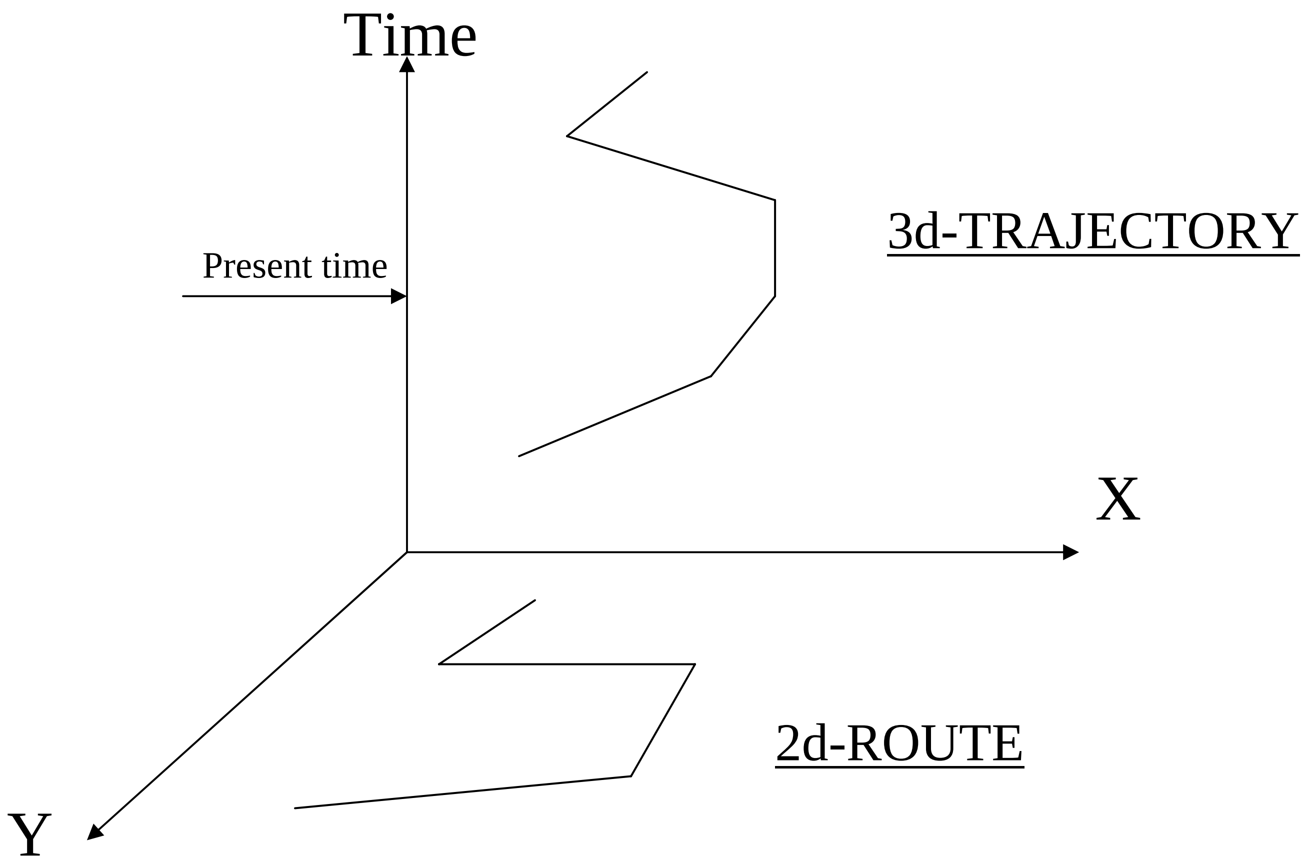
```
SELECT *
FROM ALL_TRIPS(source, dest) AS t
WITH STOP VERTICES is empty
WHERE number-of-transfers (t) < k
```

`OPTIMIZE` is the minimization of the sum of some numeric edge attribute (e.g., length, duration)

Can be solved with

A. Lozano and G. Storchi. Shortest viable path algorithm in multimodal networks. In Transportation Research Part A: Policy and Practice, volume 35, pages 225–241, March 2001.

Moving Objects Databases trajectory model



Different trajectory model produced variations in query languag

Need for unification

Other components of the platform

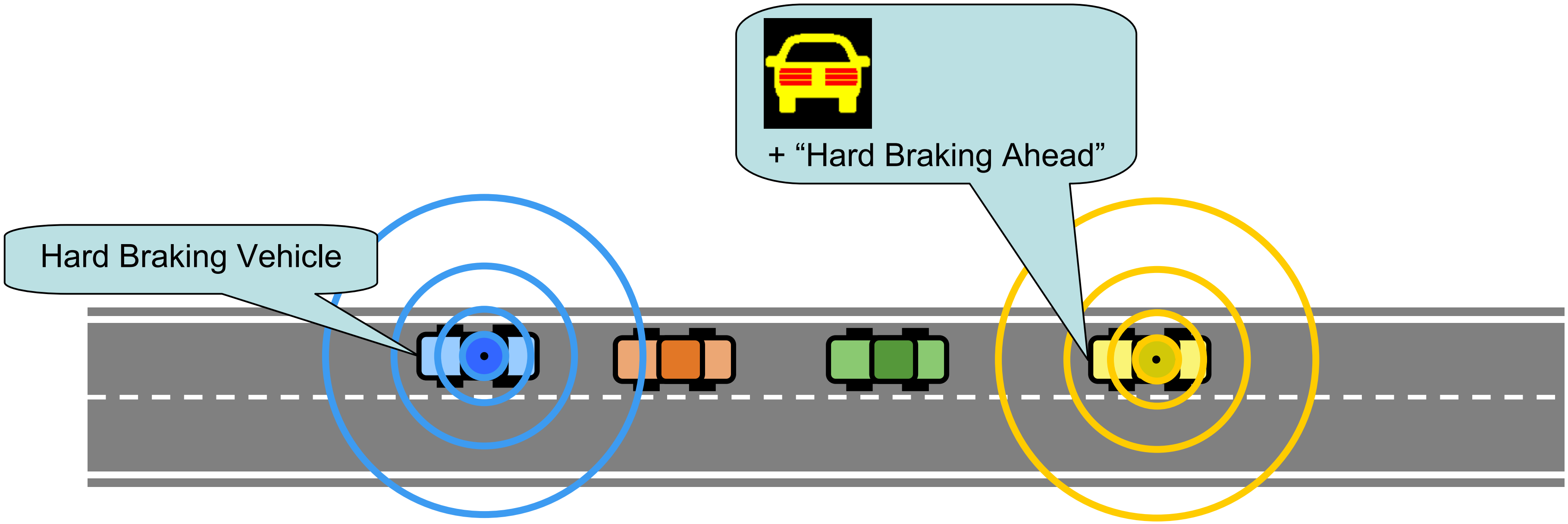
- Service discovery
- Publish/subscribe

Outline

- IntelliDrive Platform Component for
  - Trajectory Management
  - Evaluation: Electronic Emergency Brake-Light

- Mixed environments: information in vehicular/P2P/cloud networks.

Emergency Electronic Brake Light (EEBL)



Alert the driver when a vehicle ahead emergency-braked

EEBL

- Can prevent accidents and pile-ups
- Distance tradeoff
  - Too far: desensitize the driver
  - Too close: dampen benefits of EEBL
    let preventable accidents occur

Proposed method – Statistical Machine learning

- Machine learn the ahead-distance for which:

  shortly after receiving an emergency-brake report, drivers emergency-brake themselves

  - based on training stage
- Other parameters:
  - Density of vehicles
  - Speed difference between sending and receiving vehicles

Evaluation by traffic simulation

- Metrics:
  - Driver desensitization
    - how to model this human factor?
    - collaboration with psychologists

Outline

- IntelliDrive Platform Component for
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  - Evaluation: the Electronic Emergency Brake-Light case

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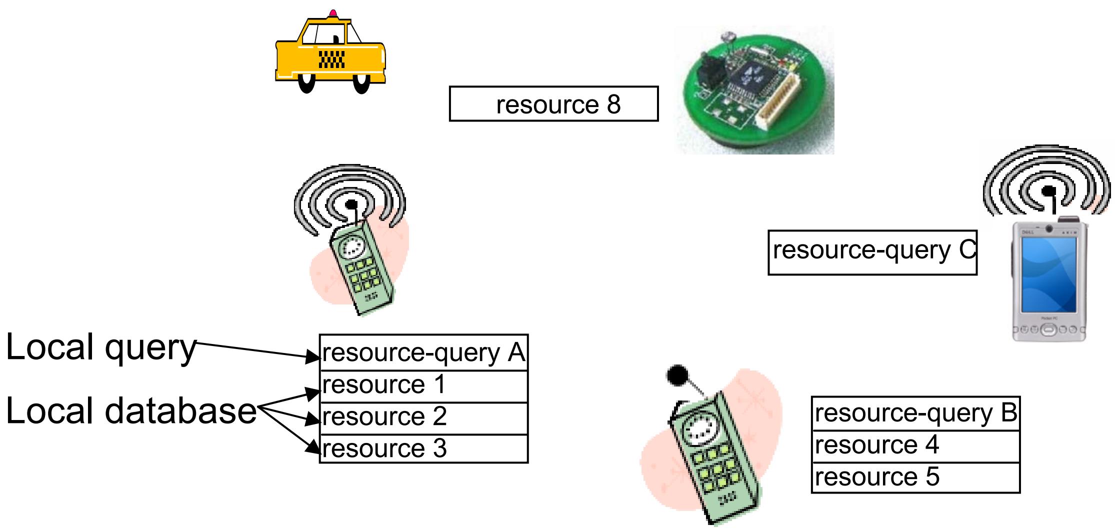
Problem

- Most Travel-information systems are client/server
- Nearby mobile devices are inaccessible
- But resources of interest are local
  - Parking slot info
  - Video of road construction
  - Malfunctioning brakelight
  - Taxi cab
  - Ride-share opportunity
- For performance, privacy, resource consumption, useful to access in P2P fashion

Environment

Pda's, cell-phones, sensors, hotspots, vehicles, with short-range wireless

- A central server may exist



Short-range wireless networks
- wi-fi (100-200 meters)
- bluetooth (2-10, popular)
- zigbee

Unlicensed spectrum (free)

High bandwidth

"Floating database"

Resources of interest
- in a limited geographic area
- possibly for short time duration

Applications coexist

Bandwidth-Power/search tradeoff

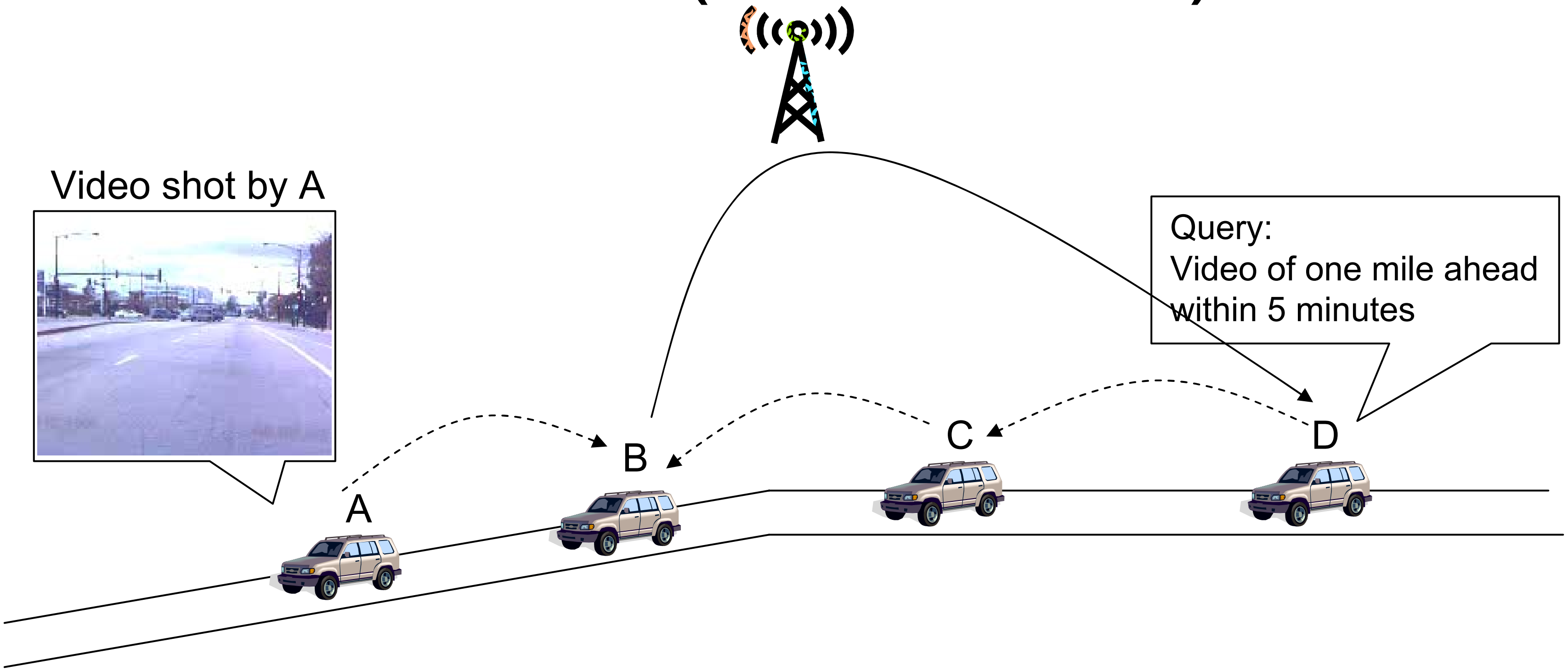
Problems in data management

- Search and Query processing
  - Combination of information push/pull
  - Information ranking

- Participation incentives (reputation, virtual currency)

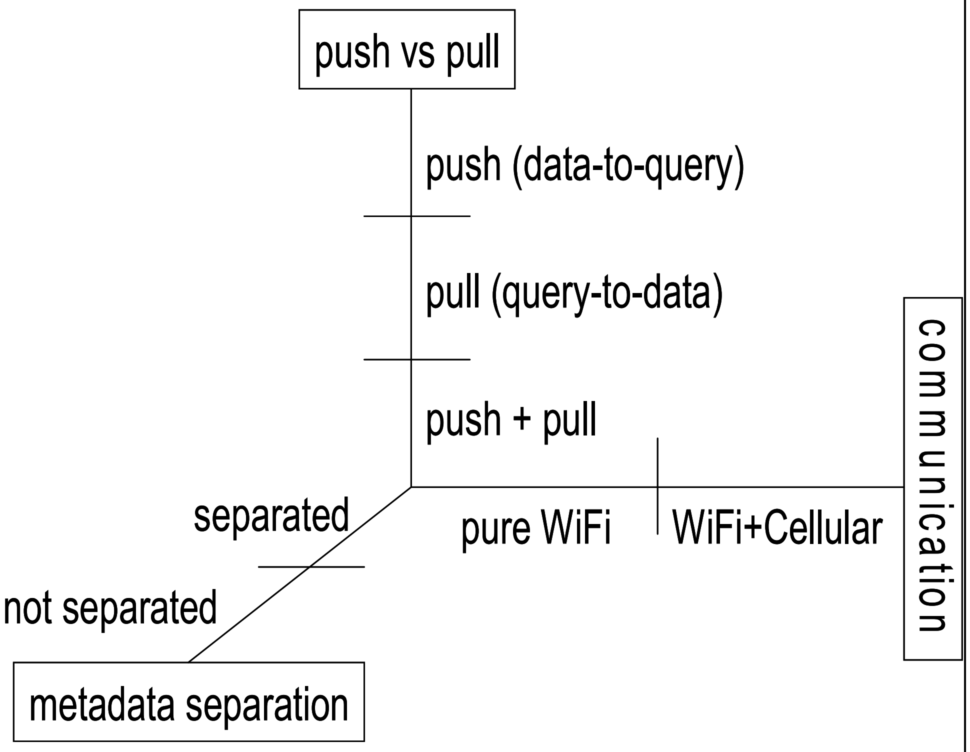
Example application: Augmentation of Travel-time maps with mm

Addressing Unreliability/Prediction: view/hear traffic conditions 1 mile ahead (multimedia)



Query Processing Strategies

WiMaC paradigm: WiFi-disseminate,
Match
Wifi/cellular-respond



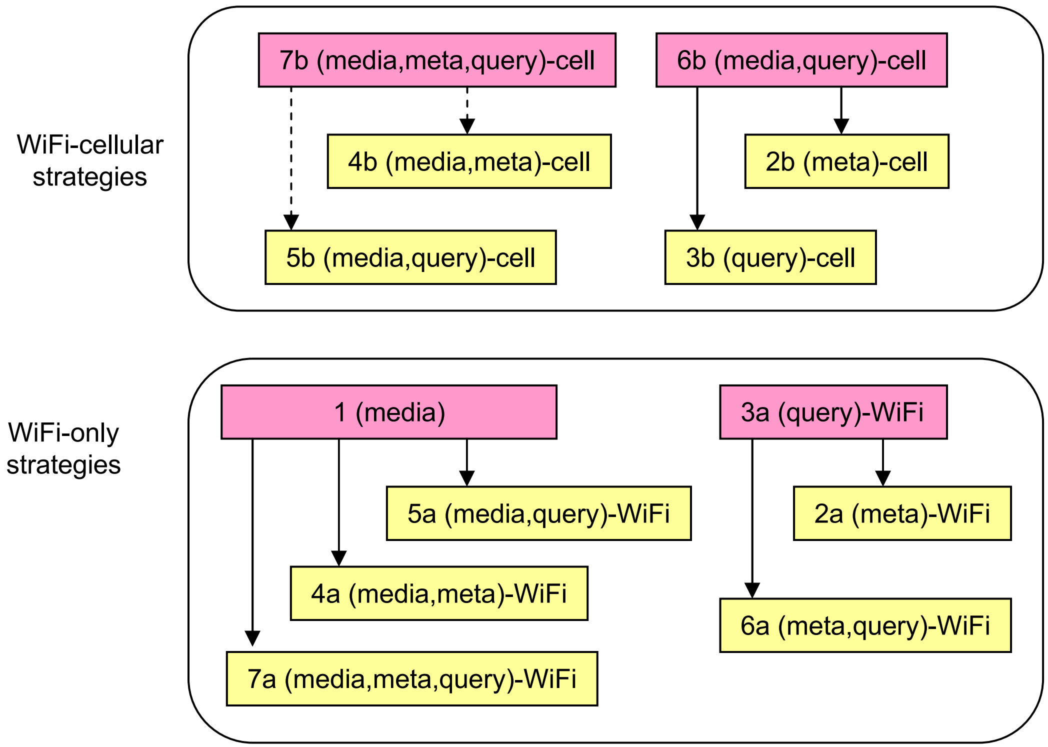
WiMaC Design Space

No.	Type of reports disseminated in the first stage (always via Wi-Fi)	Communication medium in the second stage
1	(media)	No second stage
2	(meta)	WiFi (2a), cell (2b)
3	(query)	WiFi (3a), cell (3b)
4	(media, meta)	WiFi (4a), cell (4b)
5	(media, query)	WiFi (5a), cell (5b)
6	(meta, query)	WiFi (6a), cell (6b)
7	(media, meta, query)	WiFi (7a), cell (7b)

Evaluation criteria:
- Throughput
- Response time
- Wi-Fi communication volume
- Cellular communication volume

Comparison Results

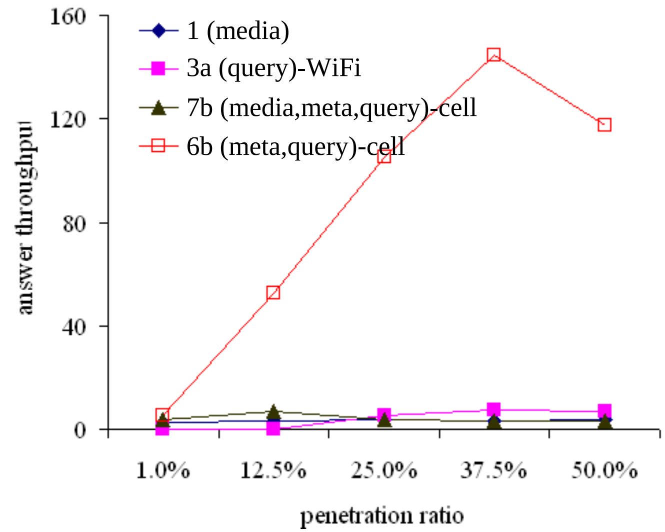
dominance analysis

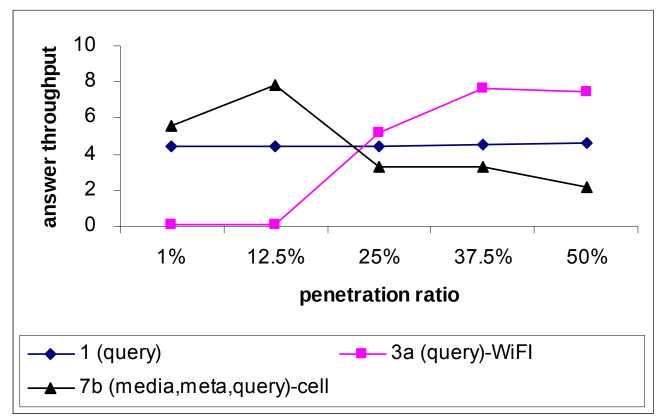


X ——▶ Y: Strategy X dominates strategy Y

X - - -▶ Y: Strategy X weakly dominates strategy Y

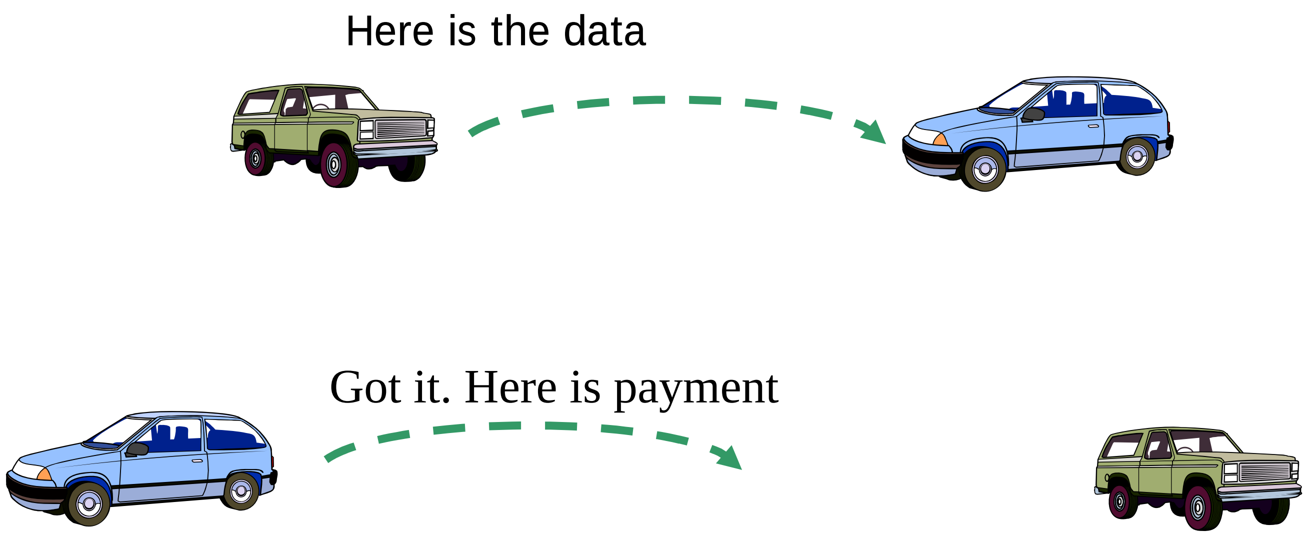
simulations





Participation incentives: Atomicity Issue in payment

- Commit protocol may not complete, leaving one participant not knowing the final status at the other participant.



Still issues to be resolved

- Local search for IntelliDrive
- Participation incentives (virtual currency)

Conclusion

- ITS/IntelliDrive potentially transformative tech
- Platform Component for Trajectory Management based on Database Systems
- Evaluation challenge: the Electronic Emergency Brake-Light case
- Mixed environments: information in vehicular/P2P/cloud networks.

Vision of the future: seamless/frictionless urban transportation