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

MUST HAVE SOMETHING TO DO WITH WIRELESS TECHNOLOGY...
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](http://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 deficient

• 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

```sql
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 (ti, mapj) 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 \((t_i,\text{map}_j)\)

- Evaluate non-temporal conditions and if \( W = \text{‘true’} \) or \( \text{‘false’} \), then done.
- Otherwise split trip into legs: \( L_1, v_1, L_2 \)
- \( L_1 \) has departure \( y_1 \) and duration \( z_1 \)
- \( L_2 \) has departure \( y_2 \) and duration \( z_2 \)
- \( y_1 > 8\text{pm}, y_2 + z_2 < 10\text{pm}, y_2 - y_1 - z_1 > 10\text{mins} \) defines a region \( S \) in \( \mathbb{R}^4 \).
- 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
\[
\int_S f(y_1,z_1,y_2,z_2) \, dy_1 dz_1 dy_2 dz_2
\]
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

Moving Objects Databases
trajectory model

Different trajectory model produced variations in query language
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

Hard Braking Vehicle

+ “Hard Braking Ahead”
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
  – Trajectory Management
  – Evaluation: the Electronic Emergency Brake-Light case

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

“Floating database”
Resources of interest in a limited geographic area possibly for short time duration
Applications coexist

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

Unlicensed spectrum (free)

High bandwidth

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: Video of one mile ahead within 5 minutes

Video shot by A
Query Processing Strategies

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

WiMaC Design Space

<table>
<thead>
<tr>
<th>No.</th>
<th>Type of reports disseminated in the first stage (always via Wi-Fi)</th>
<th>Communication medium in the second stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(media)</td>
<td>No second stage</td>
</tr>
<tr>
<td>2</td>
<td>(meta)</td>
<td>WiFi (2a), cell (2b)</td>
</tr>
<tr>
<td>3</td>
<td>(query)</td>
<td>WiFi (3a), cell (3b)</td>
</tr>
<tr>
<td>4</td>
<td>(media, meta)</td>
<td>WiFi (4a), cell (4b)</td>
</tr>
<tr>
<td>5</td>
<td>(media, query)</td>
<td>WiFi (5a), cell (5b)</td>
</tr>
<tr>
<td>6</td>
<td>(meta, query)</td>
<td>WiFi (6a), cell (6b)</td>
</tr>
<tr>
<td>7</td>
<td>(media, meta, query)</td>
<td>WiFi (7a), cell (7b)</td>
</tr>
</tbody>
</table>

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

dominance analysis

WiFi-cellular strategies

1 (media)

3a (query)-WiFi

4b (media,meta)-WiFi

6b (media,query)-cell

2b (meta)-cell

5b (media,query)-cell

3b (query)-cell

WiFi-only strategies

1 (media)

3a (query)-WiFi

4a (media,meta)-WiFi

5a (media,query)-WiFi

6a (meta,query)-WiFi

7a (media,meta,query)-WiFi

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

X Y: Strategy X dominates strategy Y

X Y: Strategy X weakly dominates strategy Y

penetration ratio

answer throughput

penetration ratio

answer throughput
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