THE UNIVERSITY OF MELBOURNE

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Collaborative Transportation: A Case for Computational Transportation Science

AMSI Workshop on Mathematics of Transportation Networks

Computational transportation science

Sixth ACM SIGSPATIAL International Workshop on Computational Transportation Science

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Tue, 2013/05/28 - 4:19pm — steve.liang

6th ACM SIGSPATIAL International Workshop on Computational Transportation Science

November 5, 2013, Orlando, FL, USA

Held in conjunction with the

21st ACM SIGSPATIAL International Conference on
Advances in Geographic Information Systems (ACM SIGSPATIAL GIS 2013) November 5-8 2013 - Orlando, FL, USA.
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Collaborative urban transport

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Collaboration

- communication* for sharing transport resources and reducing load in networks
- apps: ride sharing, car sharing, demand-responsive transport, collaborative freight, …

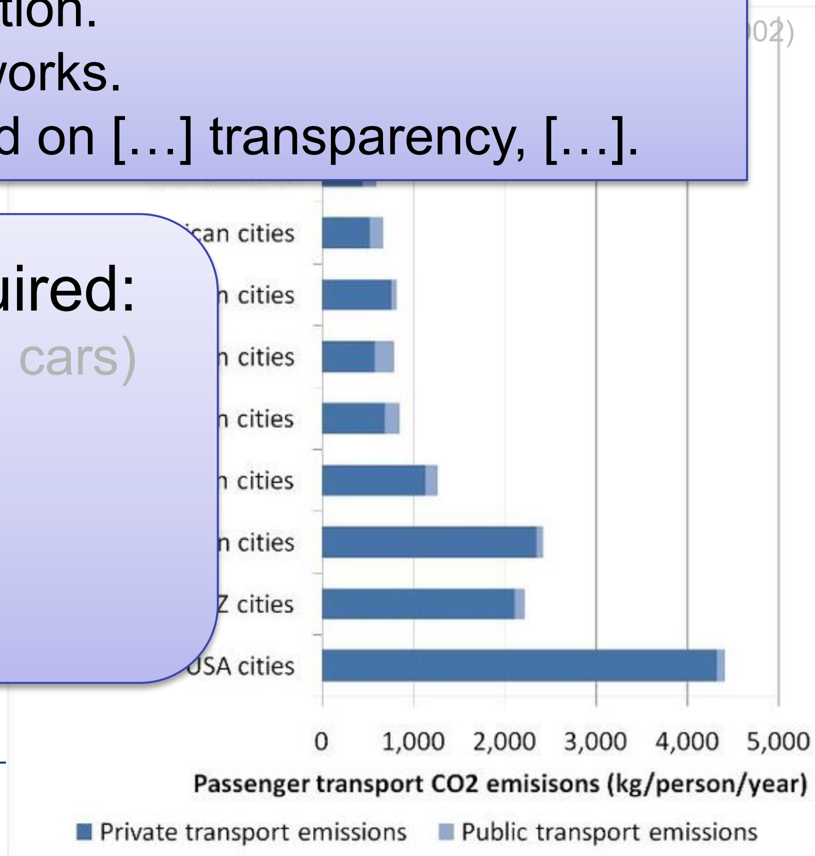
* V2V, V2I, V2P, P2P, P2I

General knowledge …

- 23% of world energy-related GHG emissions

Melbourne Principles for Sustainable Cities (UNEP & ICLEI 2002)

- Enable communities to minimise their ecological footprint.
- Empower people and foster participation.
- Expand and enable cooperative networks.
- Enable continual improvement, based on […] transparency, […].



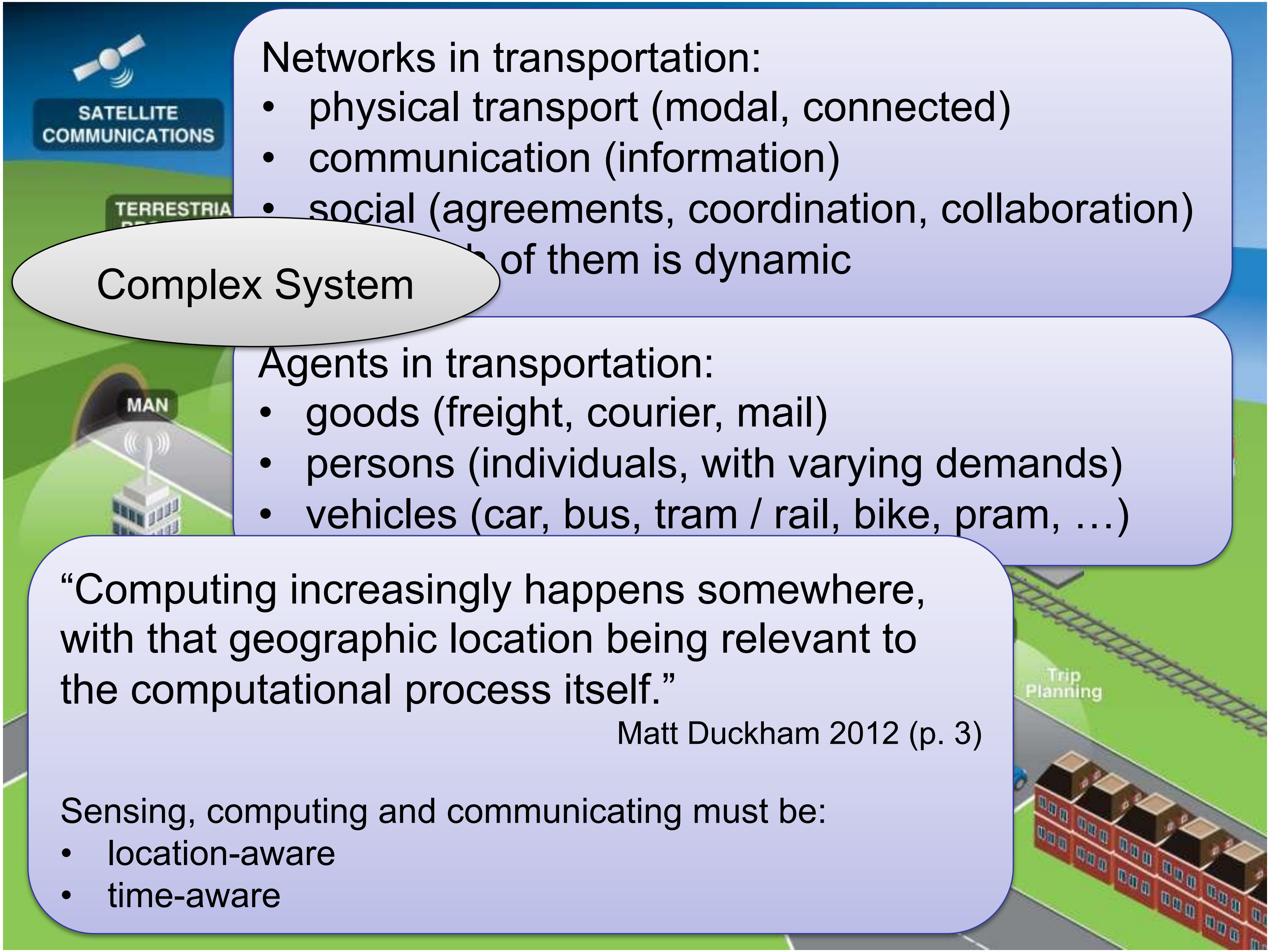
Sustainable urban transport required:

- urban densification (less reliance on cars)
- investments in urban transit
- electrical vehicles
- …
- collaborative transport

Collaborative urban transport

- bottom-up
  - working with available infrastructure and systems
  - potentially disruptive to current challenges
- better utilization of capacity
  - with environmental, equity and economic benefits

- real-time sensing
- connectedness
- information fusion
- intelligent search, discovery and control
- intelligent and persuasive interaction



Networks in transportation:

- physical transport (modal, connected)
- communication (information)
- social (agreements, coordination, collaboration)
- … of them is dynamic

Complex System

Agents in transportation:

- goods (freight, courier, mail)
- persons (individuals, with varying demands)
- vehicles (car, bus, tram / rail, bike, pram, …)

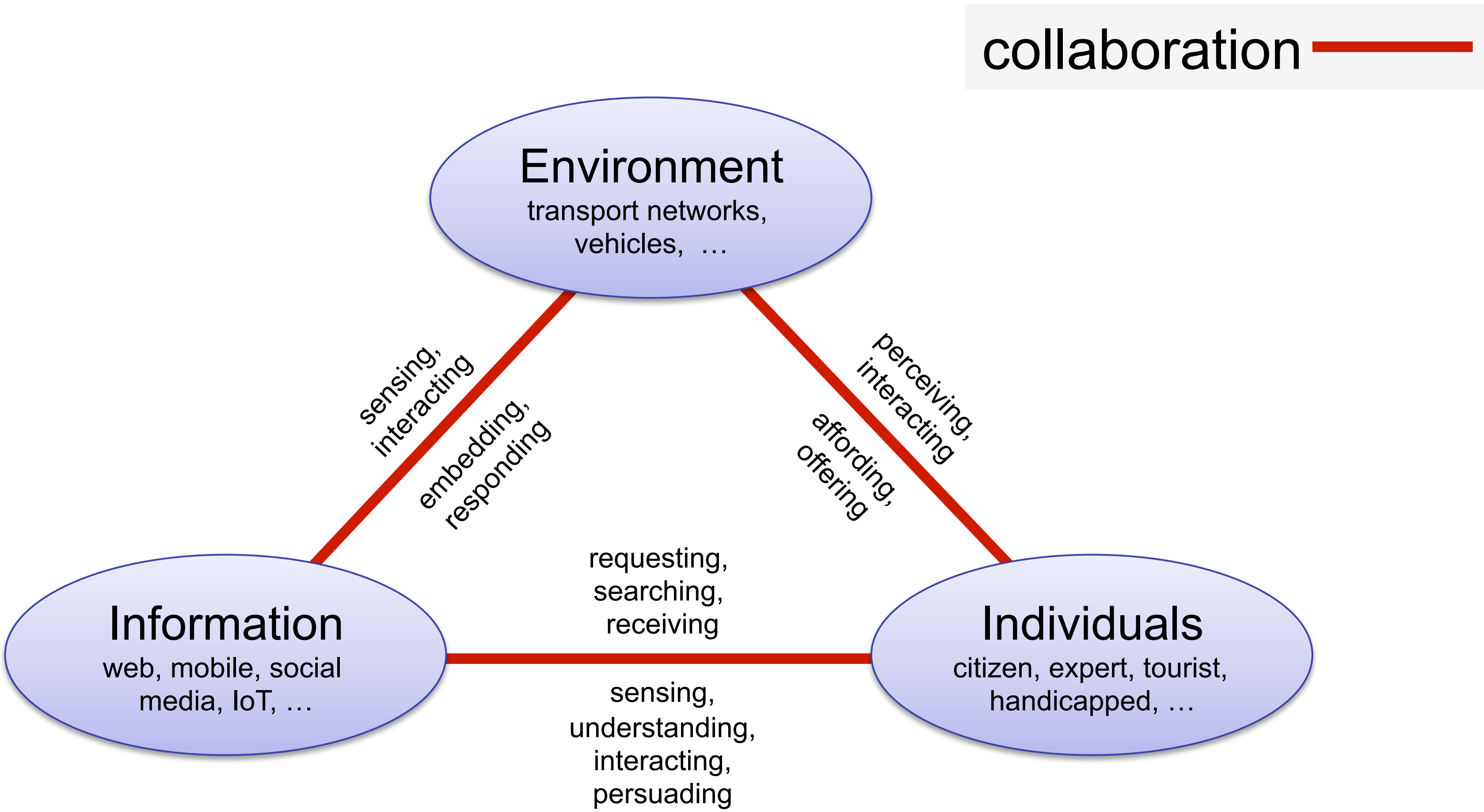
"Computing increasingly happens somewhere, with that geographic location being relevant to the computational process itself."

Matt Duckham 2012 (p. 3)

Sensing, computing and communicating must be:

- location-aware
- time-aware

Transport in the complex system "city"



10 core concepts

- location
  - multiple ref systems
  - salient locations
- neighborhood
  - flexibility in space, time, intention
- field
  - dynamic; macro-models
- object
  - people (entering and leaving); intentions
- network
  - dynamic
  - lane change, indoor, inter-modal, …
- event
  - varying impact
  - unlikely
- granularity
  - suburb-suburb ↔ door-door
  - macro vs micro
  - obfuscation, privacy
- accuracy
  - localization
  - sample size
  - choice behavior
- meaning
  - knowledge extraction
  - UI: “stopped for a coffee”, “the store near the theatre”
- value
  - footprint
  - costs / fares
  - ease of use

(Core concepts of spatial information, Kuhn 2012)

4 core challenges

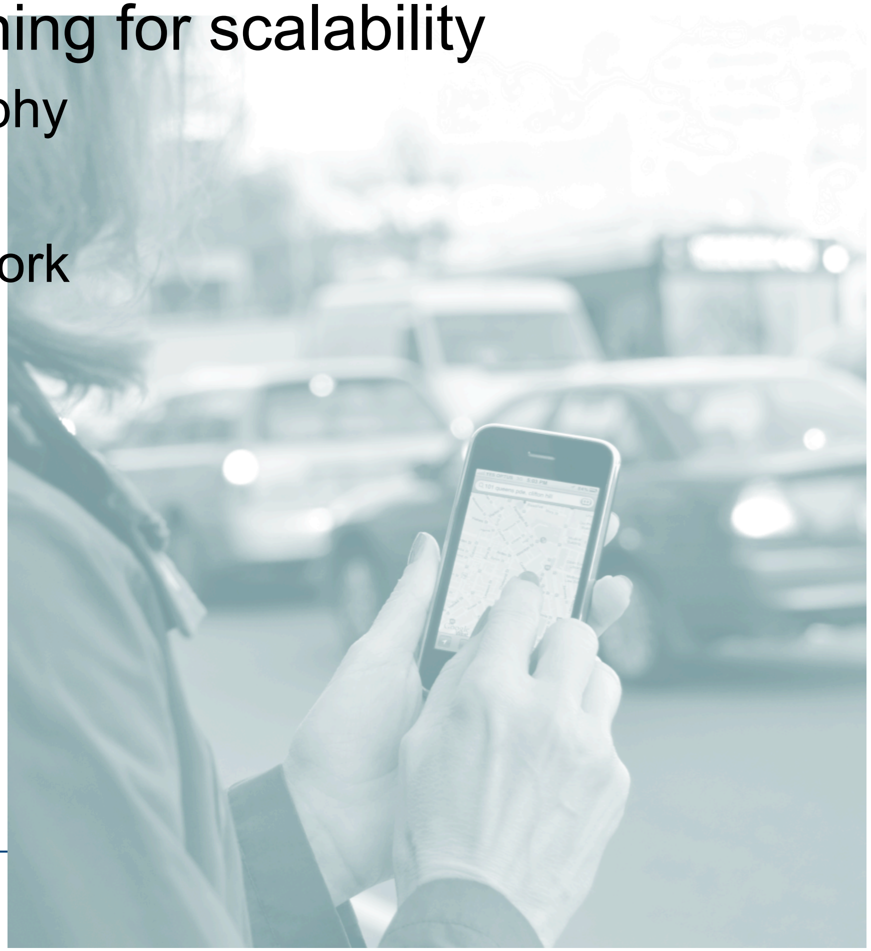
- Modelling transport networks
  - e.g., centrality
- Modelling transport on networks
  - e.g., people
- Optimization
  - e.g., collaboration on demand
- Interaction design
  - e.g., persuasion / ease of use

Examples from our research

1. ride sharing
2. bus on demand
3. opportunistic interaction design
4. collaborative evacuations

#1 – Ride sharing

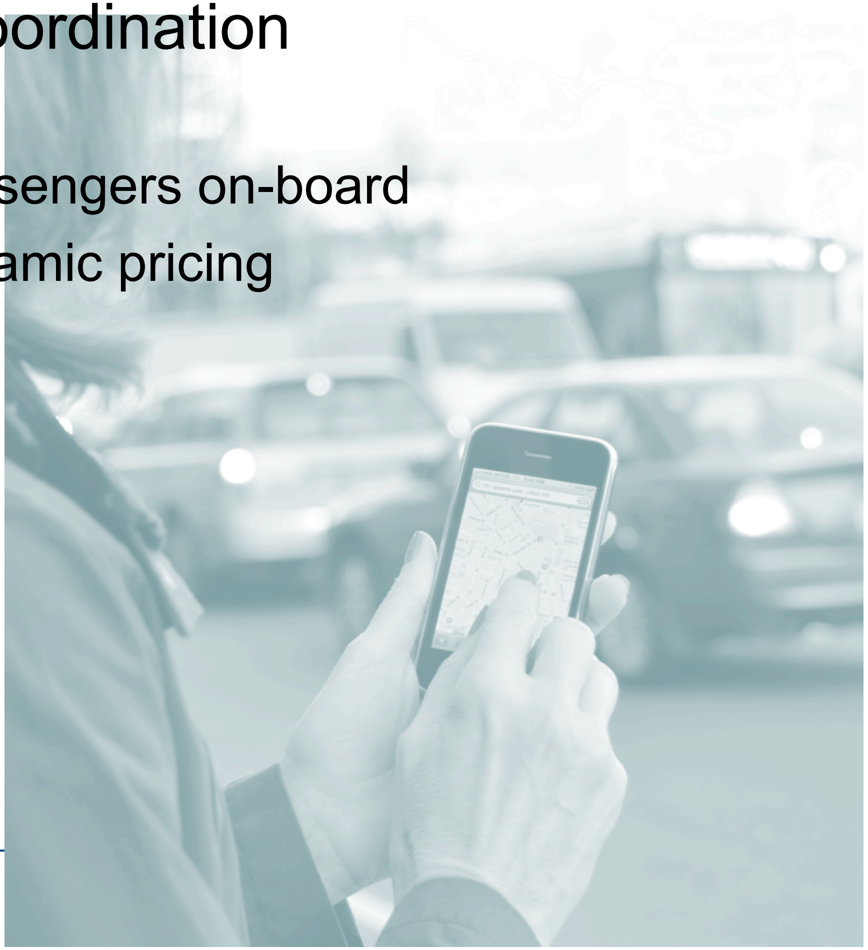
- real-time decision making
- decentralized (local) planning for scalability
  - exploiting 1st law of geography
  - local knowledge
  - fragile communication network
- results:
  - with transfers: travel times close to global optimum



#2 – Bus on demand

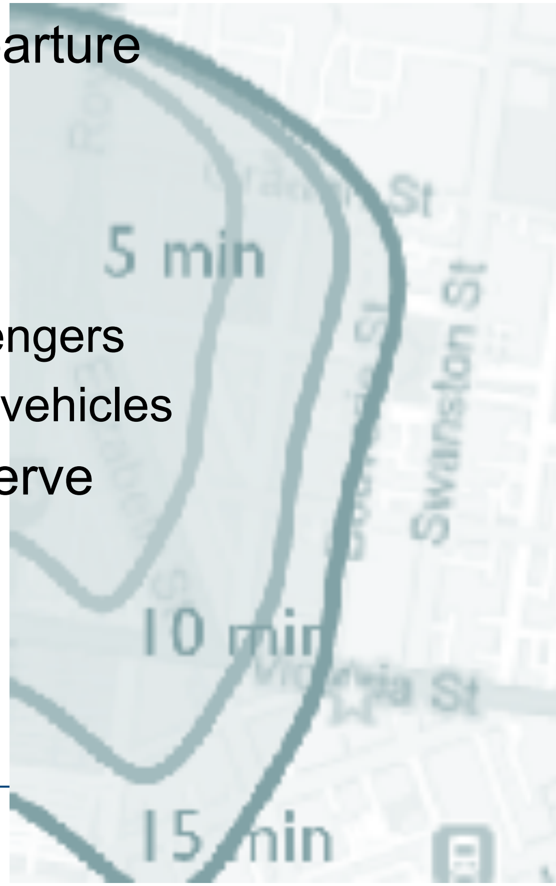
– real-time decision making
– centralized planning for coordination
  - optimization across fleet
  - constrained by QoS for passengers on-board
  - QoS can be relaxed by dynamic pricing

– results: preliminary



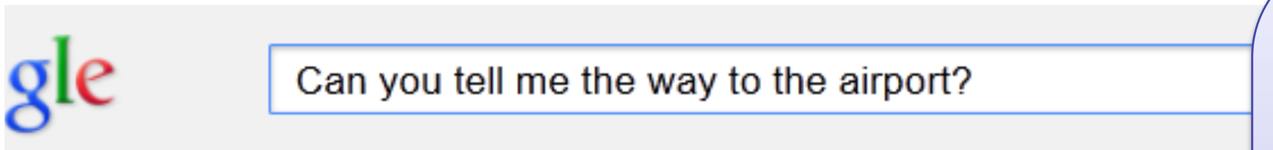
#3 – Interaction design (a)

- real-time decision making
- passenger chooses vehicle
  - pre-selected by destinations, time of departure
  - vehicles have flexibility:
    no fix time or location of departure
  - privacy preserving
    - offering vehicle should not identify passengers
    - searching passenger should not identify vehicles
  - fragile over near future: first-come first-serve



#3 – Interaction design (b)

- “intelligent” spatial communication
- enabling the machine to:
  - understanding people
  - communicating to people in their terms



Sure. Tullamarine, you mean? Follow this street [*points*] to the hospital, then turn right. From there, just follow the signs.

#4 – Collaborative evacuations

Collaborative … why?

- indoor services lack maps
- maps are outdated by event anyway
- communication infrastructure may be damaged

- solution:
  - devices track themselves (SLAM)
  - devices share their knowledge via short-range radio
  - iterative route planning and random search

Conclusions

Collaborative transportation:

- why:
  - sustainability
    (environmental, equity and economic benefits)
  - resilience
    (safety benefits)
- how:
  - urban connectedness
    (sensing & communication & fusion & smart search)
- and where is the maths:
  - optimization within spatial, social and economic framework
  - user behaviour

Some future questions

- leverage points?
  - urban areas / characteristics?
  - numbers of participants?
  - pricing?
  - safety?
- integration?
  - data fusion
  - transport modes
  - user groups / contexts
  - competing platforms

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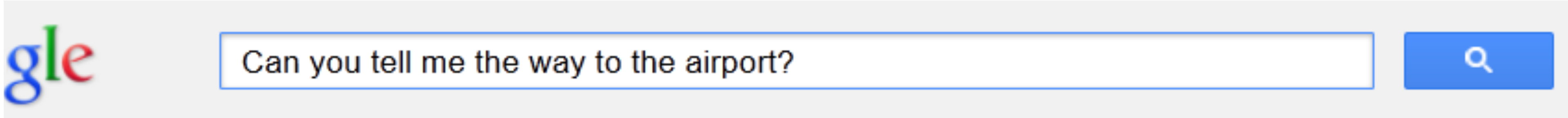
Sustainable urban transport

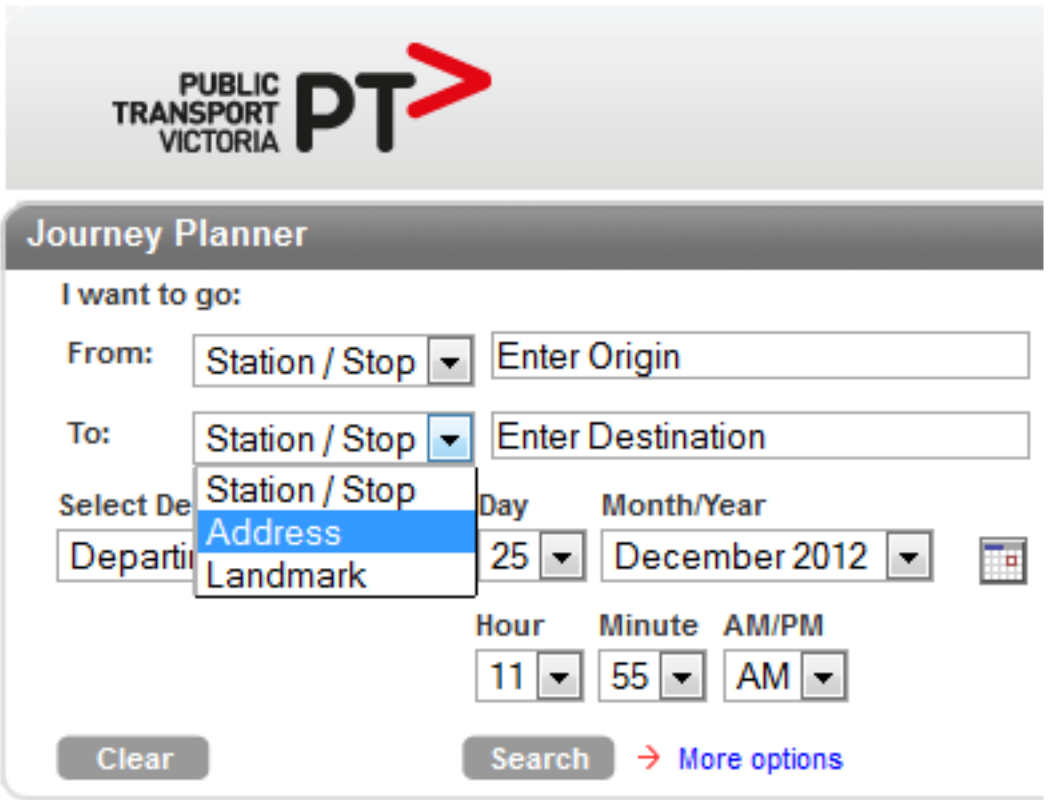
- Sustainability: an aspiration
  - environmental, social equity and economic demands

(UN World Summit 2005)

- the environmental demands:
  - urbanization/sprawl, space, energy, emissions, …
- the social equity demands:
  - accessibility, mobility, equity among groups, …
- the economic demands:
  - costs, time, health, …

#3 – Interaction design (c)





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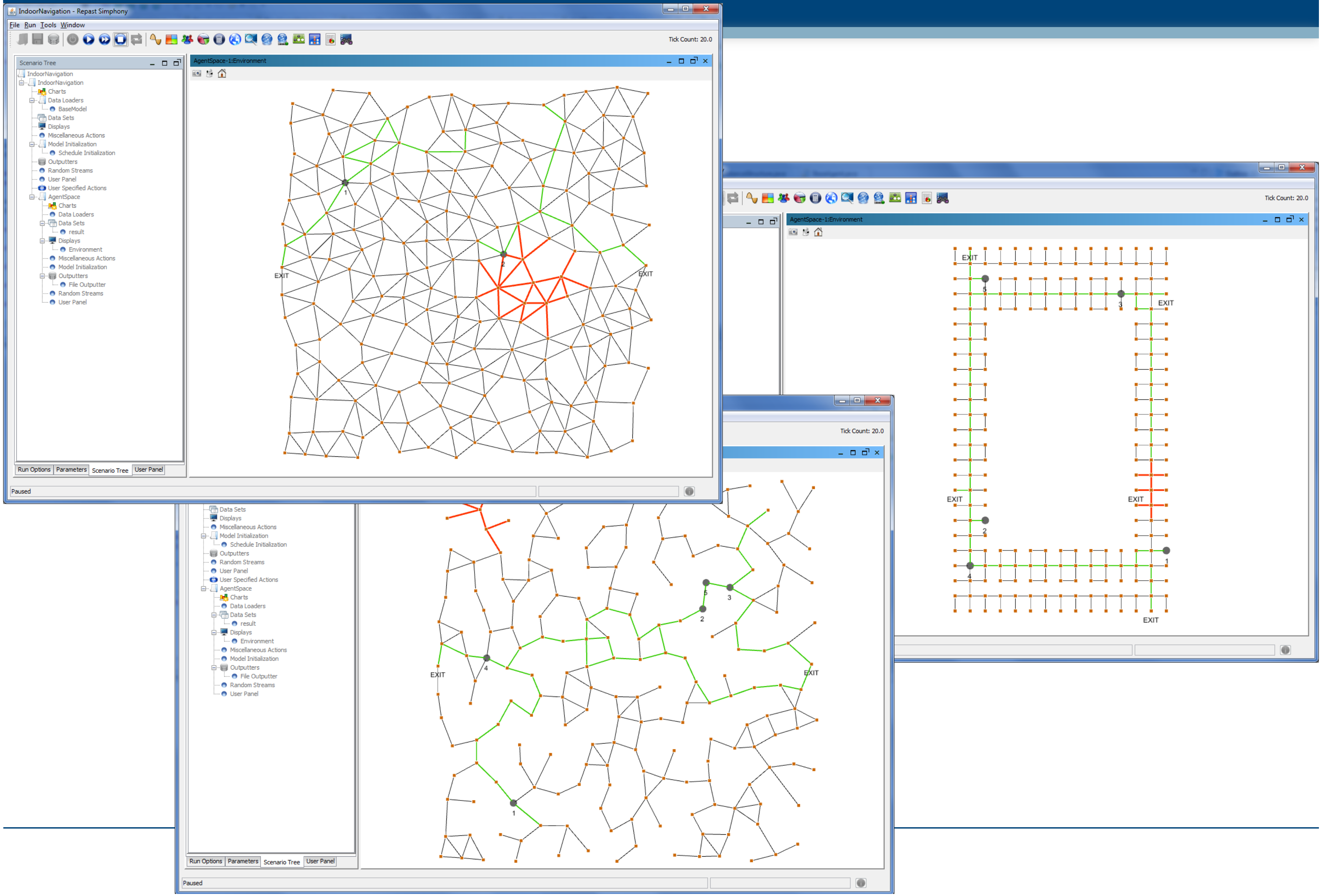

Collaborative urban transport

bus on demand

ride sharing

car sharing

freight collaboration

feeder / modal integration

Core concepts of CTS

Core concepts of spatial information

- identified by Kuhn (2012)
- spatial concepts:
  location, neighborhood, field, object, network, event
- information concepts:
  granularity, accuracy, meaning, value

Are these concepts relevant for computational transportation science?

- challenges for mathematics?
- foundations for algebras?

Core concept #1: Location

- relation of *figure* to *ground*
- *ground* and *relation*: context-dependent

CTS:

- multiple reference systems
- salient locations

Core concept #2: Neighborhood

- space is autocorrelated
- nearness is context-dependent

CTS:

- expands in time and intention
- flexibility in space, time and intention

Core concept #3: Field

- function (scalar or vector attributes) of space

CTS:

- expands in time
- macro models: supply / demand as densities

Core concept #4: Object

- (dual to field)
- individuals with spatial, temporal and thematic properties

CTS:

- objects of high fragility (entering/leaving transport)
- intentions as an attribute
- micro models: supply / demand as agents

Core concept #5: Network

- relations between objects
- G(N,E), with both N and E having spatial, temporal and thematic properties

CTS:

- transportation networks …
  - Lane change? Turn restrictions? Indoor spaces? Transfer between modes?
  - everything in the city is dynamic: physical networks, demand, economy, …

Core concept #6: Events

- changes to previous core concepts
- (events : processes) ~ (objects : fields)

CTS:

- Events in transportation networks
  - largely varying impact
  - unlikely – hard to predict
  - infrastructure (incl communication), vehicles, people

Core concept #7: Granularity

- precision
- applies to each spatial core concept
- involves spatial, temporal and thematic attributes

CTS:

- macro ↔ micro simulation (demand, supply)
- localization (space and time), obfuscation
- access, privacy

Core concept #8: Accuracy

- correctness
- applies to spatial, temporal and thematic attributes

CTS:

- transport as a complex system
- sample size
- localization (space and time)
- choice behavior

Core concept #9: Meaning

- interpretation of information
- involves spatial, temporal and thematic attributes

CTS:

- agents (‘vehicle’, ‘person’, ‘mode’, …)
- intentions (“perhaps a coffee on my way to work”)

Core concept #10: Value

- social / emotional attachment to information

CTS:

- sustainability, footprint, health
- ease of access, ease of use
- economic costs and benefits