Formal Encoding of a Multi-Modal Trip with the Use of Public Transport- A Passenger's Perspective

Elissavet Pontikakis
Institute for Geoinformation and Cartography, Technical University of Vienna Austria, Gusshausstrasse 27-29/127, 1040 Vienna, Austria.
pontikakis@geoinfo.tuwien.ac.at

ABSTRACT

This paper is part of a research effort that focuses on the identification of a minimum set of information needs that are required for the execution of a trip with the use of public transport. In this paper we provide a summary of the formalization efforts which render the conceptual model into formal code. Gibson's theory of perception and the notion of the four basic blocks of transport are used in the formation of the conceptual foundation in this model.

KEYWORDS: *Spatial cognition, Agent-based systems, Public transportation, Multi-modal transport, Functional programming, Cognitive agent modeling.*

INTRODUCTION

Moving around with public transport is seen as the preferred option by public officials and commuters alike. A study performed for the Austrian ministry of transport (Pontikakis, Frank et al. 2000) showed the importance of understanding the basic needs of the passengers. The current research effort was inspired by that study. This paper focuses on the formalization of a model developed to assess the needs of a commuter who uses public transportation. The second section of this paper provides a short overview of the conceptual model which consists of a passenger, a point network and a vehicle component. We model our passenger as a cognitive agent who is able to plan and form mental representations of the world. The third section describes the formal tools which are used in this effort such as the functional programming language Haskell. The fourth section defines the constituents of the formal code in association to the conceptual scheme. The final section provides the conclusions of this formalization.

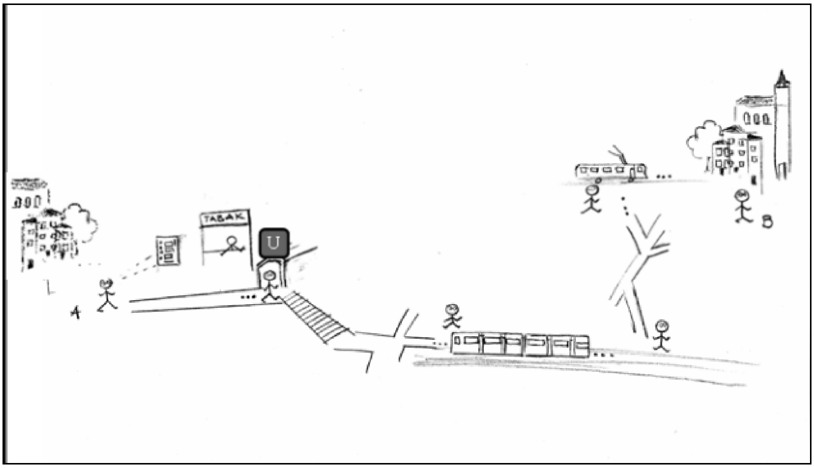

Figure 1: Overview of abstract situation.

OVERVIEW OF CONCEPTUAL MODEL

In this research we model a passenger that carries out a trip from his residence to his office building using public transport. Our conceptual scheme is comprised of a passenger, a point network and one or more vehicles. The scheme encompasses an agent-based approach where the passenger acts as a cognitive agent who is able to hold a plan and have a mental representation of his environment (Ferber 1998). Figure 1 depicts this case study.

The passenger: The passenger's locomotion is goal driven. He has average perception capabilities through which he is able to respond to the affordances within the environment that are relevant to his trip. As a result he is able to walk or to wait on a pavement, to put a coin in a slot in order to buy a ticket, to perceive the content of a sign in the front of the bus or at the bus stop indicating the bus destination, or to ascend or to descend a few step in order to enter or exit a vehicle (Gibson 1986). The above are examples of affordances that are perceptually conveyed to the passenger by the pavement, the coin slot, the bus sign, and the steps.

The passenger embarks on his trip having in mind a mental plan, namely the mental plan of his intended journey. The passenger's destination is reckoned as the plan's last entry. The mental plan is seen as a set of concrete steps that are stored in the passenger's mind (Denis 1997). In our model, the passenger uses these steps to verify his current state and to move on to a new one. The mental map represents any of the following: a set of instructions provided by another person, a set of self generated instructions after consulting a map or any type of guide, or a set of self generated instructions after comparing his intended trip to previous experiences. Ultimately, a mental plan constitutes the passenger's vision of his trip stored in his mind beforehand as a set of location points and operations associated to these points. There are cases where a mental plan for the entire trip is partially generated at the beginning and being completed as the trip goes on. In these cases, the trip could be regarded as comprised of smaller components. The passenger's mental plan is not necessary a correct plan.

The passenger also possesses some form of money and may or may not have a proof of payment for transport, namely a ticket, to qualify as a legitimate user for the services rendered within the institutional reality of the public transport system (Searle 1995), (Frank 2001). This part of the model constitutes the business aspect of the trip.

The point network: The transportation space is conceptualized as a network of points shared by the passenger and the transportation vehicles. Each point is characterized by a set of operations, namely affordances, which are associated with that point. The perception of a sign, e.g. bus line, is regarded as an affordance of the sign. The signs which are employed in this model and are of interest to the passenger's needs for locomotion are the signs indicating the vehicle's stop, line, and destination. Points which afford the same set of operations are assigned the same affordance bundle relevant to moving with public transport. For example, all intersections afford to be used for walking or waiting.

The vehicle: The transportation vehicle locomotes on its route according to a predetermined vehicle schedule. We assume that the vehicle is either in motion or at a complete stop. Our research focuses on the commuter's perspective of the trip. It is assumed that the commuter influences neither the route nor the schedule of the vehicle. However, the bus scheduling introduces the aspect of the transport provider into the model.

The four blocks of transport: We consider that the execution of a complete trip with the use of public transport from a passenger's perspective is an assemblage of four basic building blocks (Pontikakis, 2003): a) the wayfinding, b) the selection and interaction of the vehicle to enter, c) the acquiring and handling of the proof of payment of transport, and d) the exiting of the vehicle. In a multi-modal trip, each block can be repeated more than once until the passenger reaches his destination.

FORMAL TOOLS

The tools that we use in our effort to formally construe the conceptual scheme is a functional programming language, the state transition theory, and the entity relationship theory.

Functional programming: We use the functional programming language Haskell to formally code our model. The selection of Haskell was based on the facts that Haskell is a functional language with simple foundation. It provides a clear view of the central ideas for which the model is used including the abstraction of the functions and the data types, the generalization, polymorphism and overloading (Thompson 1996). Each function written can be tested separately providing so a foundation for clean programming.

State transition diagram: A state transition diagram graphically describes the passages between states. It facilitates the apprehension of each state and the identification of missing states. In this research, the state transition diagram is used as a state identification tool for both the passenger and the vehicle.

Entity relationship theory: We apply the entity-relationship theory to identify the associations among the elements of the point network and among those and the operations which are afforded by each point (Chen 1976). The connectivity between two entities, namely the direction of the relationship, describes the mapping of associated entity instances. We use these associations among elements to generate and access the elements in our data structures. The relationships define the semantics of the data and provide the access paths that lead to the entities of interest (Nievergelt and Hinrichs 1993). The identification of an attribute value can be achieved by recursively identifying entities through their relationships. For details about the entity-relationship theory readers are referred to (Chen 1976) and to the web site mentioned in the footnote[43].

FORMAL ENCODING

Components of the formal model

The Haskell language supports the modular encoding in our formal model. A module can call other modules and can be called by others. The structure of the formal modules follows closely the structure of the conceptual scheme. Each module provides the connections to the conceptual framework of a passenger's trip with the use of public transport. The passenger-point network-vehicle conceptual model is mapped into the World, Commuter, PointNet and Vehicle Haskell modules. The four building blocks are encoded into the Operations module.

The World module

The World module calls the Commuter, PointNet and Vehicle modules and plays the role of the data type integrator.

```
module World where
import List
import Commuter
import PointNet
import Vehicle
```

The Commuter module

The Commuter module encodes the cognitive agent, namely the passenger. According to the conceptual description, the agent possesses a mental plan, a form of money, and a ticket. The Commuter module covers the agent's understanding of the world and his goal, his strategy for reaching his goal, and

[43] http://www.utexas.edu/its/windows/database/datamodeling/dm/biblio.html: Introduction to Data Modeling

his spatial and financial state. The agent's cognition of his state in association with him being in or out of a vehicle is modeled through the Boolean type StateInOutVehicle.

```
data Agent = Agent MentalPlan Pocket Ticket StateInOutVehicle ALocation
```

The data type MentalPlan models the agent's understanding of the world in the form of instructions. Before a passenger executes any trip he makes a mental plan of the spatial and operational steps that he intends taking in order to move from his origin to his destination, namely his goal. The points of origin and destination are formally included in the MentalPlan.

```
type MentalPlan = [MentalPlanEntry]
type MentalPlanEntry = (POIID, [Operation])
```

The agent's mental plan is related to a set of instructions. Each entry in the agent's mental plan represents a point, POIID, on the point network and an operation to be performed at this point of interest. Before the agent moves to a new point of interest, he looks into the next step in his list of instructions, MentalPlanEntry. The wayfinding piece has already been extensively modeled through previous work (Raubal 2001) and is simplified in this formalization. For the scope of this research, the agent's mental plan provides detailed instructions of how to locomote successfully until he perceives indications of public transport related signs. Then his mental plan instructs him to board a public transport vehicle with "x" destination and to exit at a vehicle stop "y".

The data type Pocket codes the agent's financial condition as an Integer while the data type Ticket codes his legitimation status as a user of the public transport system with a validated or non-validated proof of payment.

```
data Ticket = Ticket TicketPrice Validated deriving (Show, Eq)
type TicketPrice = Int
type Validated = Bool
```

The agent's location `ALocation` is an internal identifier of the point network data base which is described below.

The PointNet module

The PointNet module encodes the fixed point network that is shared by the commuter and the vehicle. We apply the entity-relationship theory to build a data structure of points and operations (Frank 2003 Unpublished). The point network consists of an assemblage of discrete points of interest. Each point is characterized by an ID and a set of operations that it affords, namely a set of affordances, alternatively called an "affordance bundle". The points of interest are internally associated with elements of the transportation network such as vehicle stops, lines, destinations, and routes. The vehicle schedule is also an entity of the PointNet data structure mapped by a set of discrete time values of a "clock".

```
data FixedType =
 BusStopT | BusDestT | BusLineT | AffordanceT | AffrdBundleT
     | BusStopLineT | ClockT | PointT
data OODB = OODB {lastid::ID,
  name :: RelVal Name,
  busStop :: RelID,
  busLine :: RelID,
  busDest :: RelID,
  affordance :: RelID,
  affrdBundle :: RelID,
  point :: RelVal Point,
  clock :: RelVal Clock,
  fixedType :: RelVal FixedType}
```

The identification of the semantic value of an entity of interest is achieved by recursively accessing the relationship paths (Nievergelt and Hinrichs 1993). The identify function is used to return a unique internal identifier from a semantic value while the to function returns a semantic value from an internal identifier. The from function returns an identifier from another identifier of a related entity (Frank 2003 Unpublished).

The Vehicle module

The Vehicle module encodes the transportation vehicle. Following the conceptual depiction of the vehicle, this module encompasses a route, a schedule, a location and a state of motion.

```
data Vehicle = Vehicle VehRoute VehSchedule MoveState VLocation
type VehRoute = [Int]
type VehSchedule = [Int]
type VLocation = ID
data MoveState = MOVE | STOP
```

The `VehRoute`, `VehSchedule`, and `MoveState` types are entities of the point network data structure. The list of integers for the `VehRoute` and the `VehSchedule` can be replaced by a list of internal identifiers.

The Operations module

The Operations module formally interprets the concept of the four building blocks of transport. The operations which are explicitly expressed in this module are associated with the affordances stored in the point network. The formalization of the wayfinding block (a) offers a skeletal structure of the agent's wayfinding behavior.

```
class FindNext pOIID where
    findWherePointNet :: pOIID -> PointNet -> pOIID
    findNextPointNet :: pOIID -> PointNet -> pOIID
    findWhereMPlan :: pOIID -> MentalPlan -> MentalPlanEntry
    findNextMPlan :: pOIID -> MentalPlan -> MentalPlanEntry
    findNextOpMPEntry :: pOIID -> Operation -> MentalPlan ->
    Operation
```

The selection and interaction of the vehicle for boarding (b) is based on the perception of the transportation related signs.

```
class AgentVehInteracts agent where
    isThisMyVeh :: Operation -> Vehicle -> agent -> Bool
    board :: Operation -> Ticket -> agent -> agent
```

The payment and ticket schema formalizes the semantics of the institutional processes for acquiring and handling the proof of payment of transport by a commuter (c).

```
class Payments pocket where
    testPocket :: pocket -> TicketPrice -> Bool
    payFromPocket :: Operation -> pocket -> TicketPrice -> pocket
    withDrawFromBnk :: BankAccount -> pocket -> TicketPrice ->
          BankAccount
    refillPocket :: BankAccount -> pocket -> TicketPrice ->
          pocket
class Tickets ticket where
    validate :: Operation -> ticket -> ticket
```

The exiting of the vehicle (d) similarly to block (b) is based on sign perception.

```
class ExitVeh agent where
    isThisMyStop :: Operation -> Vehicle -> agent -> Bool
    exit :: Operation -> Vehicle -> agent -> agent.
```

CONCLUSIONS

The purpose of this paper was to show that a passenger's trip from a point A to a point B with the use of public transport can be formally modeled. The formal implementation follows closely the conceptual approach. The four basic building blocks of transport appear to encompass the semantics of wayfinding, institutional reality and perception theory. Understanding the essential user's needs of a system is a critical step towards developing user friendly services with the intention of maintaining satisfied users and attracting new ones. We hope that this work will contribute to this understanding.

Future aims of this research include the integration of multi-modality of the transportation means in a more complex case study. A second aim is the development of a performance module which will regulate and document the models sensitivity to input changes. A third longer term direction is to test further the theory of the four building blocks of transport in cases that use alternative modes of public transportation (e.g., boats).

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