Modeling And Simulating Traffic From A Cognitive And Qualitative Reasoning Perspective (*)

Stefania Bandini(1), Antonella Carassa(2), Paolo Pegurri(1), Alessandra Valpiani(3)

*(1) Department of Computer Science, University of Milan
via Comelico, 39 20135 Milan Italy
tel +39 2 55006269 fax +39 2 55006276
email: bandini@hermes.mc.dsi.unimi.it*

*(2) Department of General Psychology, University of Padua
via Venezia, 8 35139 Padua Italy
tel +39 49 8276684 fax +39 49 8276600
email: carassa@ipdunidx.unipd.it*

*(3) Center for Cognitive Science, University of Turin
via Lagrange, 3 10123 Turin Italy
tel +39 11 549475 fax +39 11 549653
email: valpiani@psych.unito.it*

Abstract

This paper presents a system for traffic modeling and simulation based on a cognitive model of commonsense reasoning about everyday physical situations. The main purpose of the system is to support control activities on circumscribed traffic situations, in which several and sudden changes occur (e.g. temporary circulation occurring in urban areas). The system is able to predict the temporal evolution of a driving activity and of the global traffic density in a circumscribed but not static topological situation. The system has been developed using an Extended version of the Qualitative Process Theory (EQPT) which allows to represent, simulate and manage dynamical behaviour of drivers in presence of changeable situations.

1. Introduction

A recent and increasing area of interest for the application of Artificial Intelligence methods and techniques in traffic problems (Bielli, *et al.*, 1994) concerns several topics: from the representation of expert knowledge for traffic control to the implementation of qualitative models for simulating traffic dynamics.

Within this framework the investigation of qualitative and human commonsense reasoning about everyday physical situations (Weld, *et al.*,1993) can be extended also to traffic problems (Moreno, *et al.*, 1995; Sugimoto, *et al.*, 1992), as in classical modeling where physical models have been usefully employed, e. g., fluid-dynamics (Helbing, *et al.*, 1995).

Several reasons support the use of commonsense reasoning about the physical world in modeling traffic problems:

- traditional analytical models often show limitations in the description and computation of real life physical and traffic situations (e.g. several parameters are difficult to obtain);
- drivers' decisions are often determined by cognitive patterns depending on individual current goals and constraints (e.g. to join an important meeting or to be in a hurry), and by

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general cognitive models on the involved physical situation (e.g. causal reasoning).

The aim of this paper is to present a system for traffic modeling and simulation, based on a cognitive model of commonsense reasoning about situations usually well handled by humans (Carassa, *et al.*, 1995; Geminiani, *et al.*, 1996). This model has been created in order to give a representation and simulation framework for performing causal reasoning activities. From a cognitive perspective, the main features which characterize this model derive from the basic assumption of *causality by contact*: the physical contact between two objects (an *agent* and a *target*) is the necessary condition for determining a causal link between two events involving such objects.
The creation of a computational model based on this cognitive model requires some basic assumptions and restrictions to be adopted:

- the explicit representation of the individual components occurring in the cognitive model and their relationships;
- the possibility of switching from some condition to another by means of explicit actions activated in the simulation.

The computational environment which implements this model is an Extension of the Qualitative Process Theory - QPT - (Forbus, 1984) here applied in the cognitive modeling framework (a more formal description of the Extended QPT (EQPT) is presented in Bandini, *et al.* (1988)). EQPT introduces the explicit representation and management of actions during the qualitative simulation of processes. The causality by contact cognitive model within the EQPT computational environment allows physical situations to be simulated following a psychological approach (Carassa, *et al.*, 1995). In this paper the enhancing of the applicative spectrum of this approach by traffic control problems is presented in terms of reproducing some basic principles underlying the human reasoning about traffic situations.

The adoption of traffic computational models based on cognitive models or psychological assumptions can be found in the literature. In Espiè (1992) a psychological analysis of driving activities is reported in order to present some fundamental principles of human behaviour which allow realistic traffic situations to be modeled. From a psychological viewpoint, such principles have been studied analysing behaviours and their determinants in the complex interactions that occur during driving activities (Saad, 1992). From a computational standpoint, the developed system is based on self-organizing dynamics, featuring intelligent agents which use their own knowledge, goals, motivations and strategies to decide what to do in different situations, carrying out their autonomous tasks.

From a cognitive and qualitative representation and simulation perspective (within the Qualitative Reasoning Artificial Intelligence topic) a traffic control model based on QPT is presented in Sugimoto (1992). With respect to this approach, the proposed system (thanks to the mentioned extension) allows a direct representation and introduction of actions and objects during the simulation of a process, and the changing of current parameters associated to the involved elements of the simulation (e.g. the introduction of both static or moving obstacles on a path, the changing of the driver speed or of the road width due to an accident).

In the next section, an overview of the main components of the cognitive model representation within the EQPT computational framework is illustrated. Section 3 will present an example of the simulation results obtained using forward inference. Finally, some concluding remarks will be drawn.

2. The Representation of the Model

Following the main characteristics of the causality by contact cognitive model, the representation of its basic concepts and the modelling of traffic components will be presented. Then, the simulation mechanism based on the reasoning mechanism of EQPT will be illustrated.

2.1 The cognitive model

The causality by contact cognitive model is based on the theory of mental models (Johnson-Laird, 1983) which defines the reasoning by building and revising of models (to build and test a sequence of *examples* as a sequence of progressively more refined representations of a target situation).

It has been experimentally demonstrated that the contact between objects is the crucial aspect of physical causality, not only in perception (Leslie, 1984; Leslie, *et al.*, 1987; Michotte, 1946; Sperber, *et al.*, 1995), but also at the cognitive level of causal analysis (Geminiani, *et al.*, 1996). When human subjects are reasoning about two events that they judge as causally linked, they try to represent a physical interaction between objects. The main concern is in assigning causal roles to two specific objects (AGENT and TARGET) and to envisage how they come into contact.
A causal model represents an AGENT, a MEDIUM, a TARGET and a set of MODIFIERS, which are elements able to influence the causal reasoning. The MEDIUM is an element (or a set of them) that allows the AGENT to come in contact with the TARGET in spite of their spatial non-contiguity. For example, if the AGENT is a driver and the TARGET is its goal (e.g. the home to be reached from the office) the MEDIUM is the set of streets to be passed through. MODIFIERS are elements influencing the driver's path and distance time from its starting point to the reached goal.
It is possible to match this model with the notion of *process* introduced in EQPT.

2.2 The qualitative processes model

As defined in Forbus (1984), the fundamental components of a physical phenomenon are the objects (generic entities) involved, the relevant quantities describing important parameters of the objects, and the processes operating on or between the objects. Processes act on objects by changing their quantitative aspects. QPT has been developed within this theoretical assumption.
The main components of a process are:

- *individual entities (or individuals)*: a process is applied on them;
- *preconditions:* represent external conditions being verified to activate a process (stating relations among individuals);
- *quantity conditions*: represent relations between the involved parameters and variables to be verified when a process is activated;
- *relations:* represent constraints among quantities;
- *influences:* represent the changes of the involved quantities (the essence of a process).

All the quantities are represented in a qualitative way by the definition of a quantity space (De Kleer, *et al.*, 1984).
With respect to the causality by contact model, the TARGET, the AGENT and the MEDIUM are represented in terms of entities. The MODIFIERS can be represented both by entities interacting with the AGENT and by all the other components of QPT.
EQPT introduces another important feature in QPT: the possibility to represent and handle changes within the execution of a process by means of direct *actions*. Actions are particular processes acting on current MODIFIERS.

2.3 The model representation

Within this framework, a traffic situation can be represented by a model consisting of:

- a structural component that represents the entities, their relations and their behaviour.
  AGENT (driver);
  TARGET (final destination)
  MEDIUM (road sector with entries and exits)
  MODIFIERS (accidents, traffic lights, static or moving obstacles, and so on).
  In this component the MODIFIERS are objects able to influence the AGENT's driving from its starting point to its final destination.

- a modifiable component that represents the quantitative aspects of entities, their relations and their behaviour.
  The quantitative aspects involve:
  - physical properties (e. g., the position of the AGENT, the width of the road sector);
  - spatial and temporal physical relations (e. g. the distance between the position of the AGENT and the final destination or the interval between the start time and the arrival time).

The AGENT is represented as a solid particle; the traffic flow is considered as a fluid dragging the particle from a starting point to a final destination and the road sector as an elastic pipe (modifiable in width). The MODIFIERS cause changes on the traffic flow, increasing or decreasing its density; for example, if a dynamic obstacle hinders the

AGENT's path, it affects directly the progression of the AGENT towards the exit, slowing it down.

2.4 The reasoning mechanism

The system draws two kinds of inferences: forward and backward.

- in forward modality the initial conditions (e. g. position of the AGENT, the final destination) and some enabling conditions (e. g. heavy or light traffic) are given and the final state (the time spent by the AGENT to get to destination) has to be established;
- in the backward modality the initial and the final state are given and the aim is to define some enabling conditions evolving the model in the desired way.

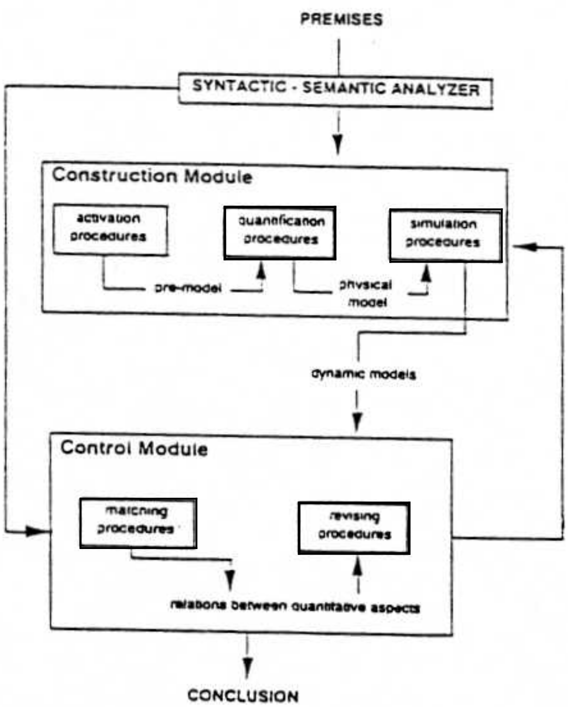


Fig. 1. The inferential system architecture

In accordance with the spirit of mental models theory, the inferential processes, drawn by the system, consist of three phases:

- a *construction* phase,which takes as input the premises expressing causal events, and generates mental models of the involved physical entities and processes.
- a *matching* phase, which receives dynamic models as input, carries out a series of comparison between them and produces as output a first conclusion.
- a *revising* phase, which evaluates the extent to which the first conclusion can be considered acceptable, by searching for counter-examples.

In order to draw such kinds of inferences, the system builds models of traffic situations, making use of data drawn from initial information about a specific situation and from its knowledge. These models evolve simulating how different influences hold. In the forward inferences, the system constructs a single model of the given traffic situation and simulates its evolution. In the backward inferences instead, the system builds alternative models, by means of revising procedures (examples), until a model is reached, which evolves in the desidered way. The cognitive theory specifies how a model can be revised (Geminiani, *et al.*, 1996), and the use of EQPT allows the computer system to represent and manage the revision of the models. The system allows to switch from a state to another by means of explicit actions activated during the simulation.
The revision proceeds by trial and error. It introduces in succession only one change. Couples of models, which differ one from the other in a single aspect are matched in order to draw the precise effect of the change. Revision proceeds by selection of changes that lead the final state of a model closer to the desired situation.

2.5 The EQPT interpreter

The system builds a model of a specific traffic situation by representing entities and assigning qualitative values to each of their quantitative parameters (EQPT allows an accurate representation of them). The behaviour of the entities and their relations are represented by processes and actions. Here the main processes are the traffic flow and the action of the MODIFIERS on this flow.
When conflicting influences act on a single quantity, EQPT is able to find out the resulting direction of change for it (Bandini *et al.*, 1988; D'Ambrosio, 1989). For example, it allows to determine how the flow density in a temporal and

spatial step is influenced by joint factors, like an exit and an obstacle. The actions describe the instantaneous changes which can occur during a process, and they allow the MODIFIERS, not present at the start time, to be introduced.

3. The Simulation

The EQPT interpreter follows two steps.

- *Activation of starting conditions* - AGENT and other entities are activated, and values are assigned. Then, the starting processes (the behaviour of the entities) are activated.

- *Modification of the quantitative aspects* - The following steps are executed, until the steady state is reached (the AGENT gets to the final destination):

  1) Control of activity: the interpreter checks if an action must be activated (it corresponds to the introduction of a new entity) or an active element must be deactivated (i. e. given the position of the AGENT some MODIFIERS become no more influential).
  2) Determination and resolution of influences: the interpreter looks for the influences in the active processes: these will contribute to the evolution from the current state to the next by changing the quantitative values of the objects on which the processes act. As an example, the flow of the traffic process contains an influence which increases, depending on the current value of density of the flow, the AGENT's vehicle position by a spatial step.

  3) Propagation of influences: when a change occurs in a quantity, all the quantities linked to it by a functional dependency are consequently changed.

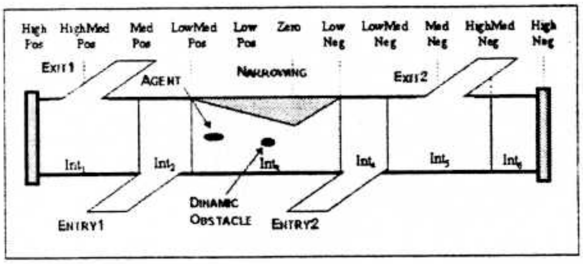
3.1 A simulation example

In this paragraph a simple simulation example will be presented and commented on. In our intentions, the system here shown suits to small size scenarios, such as traffic control on a limited traffic area with works in progress.
The preliminary phase in the preparation of a simulation consists in building a scale-model of the real traffic situation to analyze.

AGENT and TARGET will be modeled as follows:

```
agent(Name) is_a entity with
  quantities:          position(Name).

pipe(Name,E) is_a entity with
  and quantities:      length(Name) &
                       width(Name)
  and relations:
q_prop(inv,poli,length(Name),density(E)).
```



Clock: 24
Current Interval: I3
Active Processes:
Flow_out
Hinder_progress
Entry2
Exit2
Narrowing
Inactive Processes:
Exit1
Entry1

Fig. 2. A simulation example

A process called `flow_out` has to be added to the model, to represent the constant influence of the final exit and thus the direction of the traffic flow. This process will be always active.

```
flow_out(flow,A,B,E) is_a process with
  individuals:          agent(A) &
                        environment(E) &
  and s_preconditions:running
  and q_preconditions:position(A) &
                        greater_than infneg
  and influences:
      decrease(flow_out_tot(B),density(E)).
```

Referring to the case depicted in Fig. 2, an example of the entities, processes and actions definitions related to some MODIFIERS follows:

```
entry2(in2,E,I) is_a process with
  individuals:          environment(E) &
                        int4(I)
  and s_preconditions: running
  and influences:
      increase(flow_in2(E),density(E)).

exit1(out1,E,I) is_a process with
```

```
   individuals:          environment(E) &
                         int1(I)
   and s_preconditions: running
   and influences:
       decrease(flow_out1(E),density(E)).

narrowing1(r1,E,P,I) is_a action with
    individuals:         environment(E) &
                         pipe(P) &
                         int3(I)
   and s_preconditions: running
   and add_list:
       decrease(width(P),normal).

obstacle(Name) is_a entity with
   quantities:          site_obstacle(Name).

hinder_progress(hp,A,E,O) is_a process with
   individuals:          agent(A) &
                         environment(E) &
                         obstacle(O)
   and s_preconditions: running
   and q_preconditions: position(A)
             greater_than site_obstacle(O)
   and influences:
       decrease(very_weak,site_obstacle(O))&
       decrease(weak,step(E)).
```

Each entry (or exit) can be added to the model by means of a process which increases (decreases for the exits) the traffic density in a particular tract of the road, slowing down (or speeding up) the progression of the AGENT toward the final destination.
To represent street narrowing (widening) an action has to be used, which will be enabled only when the AGENT is close. In this case, the action will instantaneously decrease (or increase) the pipe width, consequently altering the density in that particular road sector and in this way modifying the AGENT speed.
Dynamic obstacles will be represented with an entity and a process. This process will directly hinder the progression of the AGENT and will be active until the AGENT reaches and overtakes the slow-moving obstacle.
Obviously, the system gives the user a way for the definition of a weight for every MODIFIER, by the assigning of values chosen from the quantity space.

To properly handle the building of a scale-model of the actual situation to simulate, the MODIFIERS should have a parameter expressing their placement in respect to the final destination.
In this way we split the road sector in "subintervals of influence" of the various MODIFIERS which will overlap. According to the AGENT position some processes will be on (the ones linked to the MODIFIERS which are, spatially, between the AGENT and the final destination) whereas some others will be off. The AGENT will thus meet, during its ride, a sequence of not-homogeneous in density subintervals, which will influence its speed, and consequently, its progression toward the final point.
With a structure of this kind, the user can even represent, coherently with the real traffic situation, the length of each subinterval.

Let's focus again on Fig. 2.
The simulation will start by assigning values to the different entities and processes according to a chosen scenario.
At each temporal step, the influences of the active processes and actions will be considered (e.g. Fig.2 depicts the simulation state at clock 24). By means of the EQPT interpreter, the system will be able to determine the resulting direction of change given conflicting influences that act on a single quantity.
The AGENT position will be then advanced by a spatial step in dependency of the value of the current subinterval traffic density (the higher the density, the shorter the spatial step). This progression will result, sooner or later, in the change of interval in which is located the AGENT, disabling the processes and the actions linked to the MODIFIERS no more influential, and so on until the AGENT gets to the final destination.
To control the modification of the AGENT position, the following code will be executed at each temporal step:

```
progression(prog,A,E,O) is_a process with
   individuals:          agent(A) &
                         environment(E) &
                         clock(O)
   and s_preconditions: running
   and q_preconditions:
            position(A) greater_than infneg
   and influences:
       decrease(step(E),positione(A)) &
       increase(very_weak,tics(O)).
```

In order to make the interaction with the system easier, a graphic interface is currently being developed. It will provide the user with simple tools to build models of specific traffic situations and with a graphical tool to monitor the simulation.

4. Conclusions

In this paper a system that models and simulates circumscribed traffic situations has been presented. The system is based on a cognitive theory of commensense reasoning about physical causality.
According to the theory, the main features of commonsense reasoning are:

- people reason by building and testing sample cases;
- people are able to create an open set of different models through revision procedures.

All these aspects are reproduced in the system: on one side the mental model level conveys the reasoning strategies (as an example the revision of the models), on the other side the use of EQPT allows mental models to be realized - as dynamical representations that involve qualitative knowledge of the physical world - in computational terms. Moreover, EQPT allows to realize the revision procedures by means of the representation and the management of actions.

The main consequence of this approach is the flexibility of the realized system in representing, simulating and managing the behaviour of drivers facing changeable situations.

The model has been developed in order to observe and control the behaviour of a single agent. To model and simulate multiagent situations the forthcoming researches will be headed into two main directions:

- applying simultaneously, in a pseudo-parallel fashion, the same model to several agents;
- joining the basic model with a distributed artificial intelligence perspective, enriching the single agents with an individual model of causality and, consequently, increasing their abilities to decide what to do in different situations. This perspective requires the definition of a class for every single agent (e.g. tropistic, knowledge based).

The system has been developed in Prolog at the Expert System Lab at the Department of Computer Science of the University of Milan.

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