COST TUD 1102 "Towards Autonomic Road Transport Supports Systems" (ARTS)

Introduction to the ARTS ROADMAP version 1.0: www.cost-arts.org/roadmap

1. Purpose

The Road Map is a major output of the "ARTS" Action and has been produced by a large subset of the ARTS community. We plan that this version is the first of several, as the construction of such an ambitious document is very much a work in progress: these documents should be regularly updated to reflect developing research areas, and to consolidate some of the sections.
Roadmap development has focused the Action's working groups research, and represents a consensus understanding of the state of the art, challenges and needed actions among Network members. Having said that, it has been written by a wide variety of authors, hence the view, the style and the angle represent the wide variety of the subject backgrounds of the writers.
Especially for early career researchers, the Roadmap should help them to get direction on their research. Additionally, the Roadmap acts a structured repository of knowledge for the Network, which members can use e.g. to provide material and references for work ranging from teaching to helping with funding applications. The Roadmap is therefore part of the legacy of the Action, and we hope its dissemination will benefit the growing community interested in the management of large heterogeneous systems such as road networks.

2. Introduction to the ARTS area

Overview: A current, well recognised societal problem is the frequent failure of road transportation networks, resulting from traffic incidents, system overloading, lack of optimised support systems, lack of information to traveller, etc. The aim of the ARTS Action is to unite and align groups across Europe from computer science, engineering and transport studies into a world leading research community that will develop new ways of designing Road Transport Support (RTS) systems based on the ideas of *autonomic systems*. If used as a platform on which to implement leading edge RTS technologies, such systems have the potential to deliver savings in the cost of system configuration, maintenance, and infrastructure, while potentially improving network efficiency and reducing the chances of human error. Using an autonomic approach to RTS is a novel and very ambitious idea requiring interdisciplinary community building, hence the need for COST, and a European dimension. Research into the many challenges of implementing self-managing systems in general, and their application to RTS in particular, has been carried out in a wide range of fragmented research areas. This Action has brought together disparate strands of research into a more integrated whole, putting Europe at the leading edge of autonomic transportation system development. Additionally, as the filed matures, it will have an effect on the existing field of autonomic computing itself that will translate to other application areas.
The ultimate challenge of ARTS, to create what is effectively a "self-aware" support system, is very ambitious, requiring co-ordination at a European level. Existing European research groups need to collaborate and co-ordinate with one-another, in order to share ideas and converge on terminology, and develop an understanding of one-another's work; before the Action there was fragmentation and lack of comprehensiveness within the often mono-disciplinary approach taken by researchers. Groups publish their work in a wide variety of outlets which is disseminated within the confines of their own communities and subject disciplines. A Roadmap is one mechanism to help unite the area.
From a research perspective, autonomic computing brings together a number of different areas in computer science and engineering, such as control theory, evolutionary computing, emergent behaviour, automated planning and scheduling, machine learning, computer vision, distributed artificial intelligence and computational intelligence. Research in these disciplines related to autonomic systems is well established, and countries in Europe have world class research groups in many of these areas. The state of the art, however, is that while technologies underlying autonomic computing have been successful in isolation, architectures and methodologies for realising it in the large have not yet been built. Meeting the challenge of engineering autonomic

behaviour in RTS systems by fusing research from these disciplines is what this Action has been engaged in doing.
Working Definitions: A system that carries out a process by itself, without human intervention, is acting *automatically*. Generally humans create automatic processes to achieve certain goals, though the system is not usually explicitly aware of what its goals are. For example a thermometer informs people of the nvironment's temperature automatically (it happily performs this process over time without anyone intervening) but it has no explicit knowledge of what it is doing; or more subtly, the thermometer does not act as if it understands its own purpose.
Nowadays, we have systems that can interact with the outside world, and carry out a process involving situations where the system makes decisions itself, based on sense data from a dynamic and unpredictable environment. In other words the system can sense, interpret the sensed data, and use that interpretation to control how the system interacts with the outside world. These systems we call autonomous, and current examples in the transport area are driverless cars and so-called "managed motorway" systems. Generally humans create the autonomous process to achieve certain goals, though the system itself need not be aware of what its goals are, or what they mean, or what its purpose is.
For more intelligent management assistance, it would be desirable if the system embodied some understanding of its own functions, and was able to *deliberate* with them. Ingrand & Ghallab, in the context of robotics, neatly capture this idea by stating that autonomous systems that have a diverse function require deliberation [1]. Human operators could then communicate service expectations to the system (such as to keep to certain limits of road congestion or emissions of pollutants), and in response the system would assess its performance against expectations, derive outstanding goals to achieve from this self-assessment, and plan how to act in order to achieve its goals while protecting its currently achieved goals. We also require that the system be able to carry out and monitor the execution of those plans, and learn and adapt from its experience. A system that displays these kind of self-management properties we call "autonomic".
Whereas we are concerned with transportation systems that are constituted with hardware and software, autonomicity as a separate and distinctive system feature was originally put forward as an important system design objective in the context of computer software systems. Such desirable system features had been discussed by other researchers, but in order to characterise system automation that goes beyond the traditional notions of automatic control, it was IBM through their Autonomic Computing vision who characterised the properties of such systems and subsequent initiatives that promoted autonomics and supported their development in the computer systems domain.

3. Structure and Contents

The Roadmap is structured into four major sections (summarized below), reflecting to some degree the areas of endeavor covered by the ARTS's working groups. The Roadmap includes the main challenges to be overcome to enable the exploitation of ARTS, and directions for engaging these challenges. Aspects of the Roadmap describe the scope of the ARTS area, the state of the art in ARTS research, and some current applications and guidelines for good practice.

Section 1 *Foundations of Autonomic Systems* is taken from the view of subject areas that may be useful in the implementation of autonomic system properties, and architectures and methods which may be used to implement them. Currently there are three areas covered in Section 1: Artificial Intelligence (taking a centralized perspective), Multi-Agent systems (taking distributed AI perspective), and Game Theory. After a discussion of each area, a set of challenges and actions are proposed specifically for implementing ARTS.
In the subsection on **Artificial Intelligence**, a wide range of techniques are covered, including Uncertain Reasoning, Rule-based Systems, Evolutionary Computing and Machine Learning. Of particular focus are techniques used in the general area of Automated Planning and Scheduling, as these are of particular importance for a self-Management function. Supporting this, there is also a section describing how to engineer knowledge, particularly knowledge of action and change.

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[1] "Deliberation for autonomous robots: A survey" F.Ingrand & M.Ghallab, AI Journal, November 2014

The **Multi-Agent Systems** subsection explains how this approach attempts to sidestep the problems of complexity using traditional control engineering approaches, by de-centralization of the problem into numerous agents, with each agent having a simple problem to solve.
Game Theory is covered in the next section: here we consider transport scenarios to be populated by several independent and self- interested agents. The actions performed by each agent may affect the behaviour of, at least, some of the other agents. We assume that the vehicles (agents) can communicate with each other, and game theory is used in the study of the interactions between these communication devices.
In future versions of the Roadmap, we would expect to cover the viewpoints from Autonomic Computing, Service Oriented Software Engineering, Data Fusion and Interpretation, Knowledge Extraction and Control Engineering. Other control-centred applications areas have that have used an autonomic / autonomous approach (e.g. in Power distribution[2]).

Section 2: *Autonomic Systems: A transportation perspective* This, the most substantial section, approaches the issue of how to implement autonomic properties in road transport support systems as a evolution of ITS. Taking a transport studies perspective, it investigates the great progress already made in making road systems more "intelligent", such as in smart motorways and signal control.
AI for ITS is a section detailing the current use of AI techniques in transportation systems. It is clear that the range of techniques (neural networks, fuzzy logic controllers) are influenced by Control Engineering community, with other promising techniques often used in AI itself (such as those in Automated Planning) not yet utilised.
Sections on **Mobile Technologies** examine the place of autonomicity in the world of connected vehicles and (hand held) information devices, where traveller behaviour change is the main effect.
Motorway Traffic Control given its simplicity compared to Urban Area traffic flow, has been an area where intelligent systems have already made benefits, in such areas as ramp metering and self-managing (SMART) systems on motorways. The section on **Junction Traffic Control** likewise illustrates a promising line of development over the years from the initial development of adaptive technologies such as SCOOT 30 years previous. A section on **Autonomic Control of Electric traffc** illustrates the unique possibilities of precision control that make rolling out systems with autonomic properties more feasible through fleets of electric vehicles.
Finally, a subsection on **Incident Detection** considers the obstructions or restrictions to traffic flow, usually caused by accidents, and investigates automatic methods for their detection and management.

Section 3: *External Factors, Environmental Benefits and Application Scope***.** This seeks to answer such questions as "What are the trust and legal issues?" "What are the current applications in autonomy?", e.g. in planes and cars, and can we use that knowledge to quantify the benefits of an autonomous approach in general to transportation; "What are the social benefits, and potential benefits to Environmental Concerns, of ARTS". This section focuses on issues of system liability and legal, institutional and political concerns of potential ARTS systems. It will produce details of the quantification of benefits of ARTS infrastructure, and investigate the relationship between ARTS and traditional systems engineering approaches.
The **External Systems Characteristics** theme is concerned with properties of the system that a user or the service is concerned with – is it safe and legal, for example.
Next up, a section investigates the **Potential Scope** of applications of ARTS, and the development of a hierarchy of application areas that is amenable to autonomic techniques. For example, some areas may be considered more naturally amenable to autonomic techniques, such as local and regional control centre planning support, and real time traffic control. Others, relying significantly on human judgement, might be more difficult to implement. A large amount of focus in these sections is on the environmental damage caused by traffic, and how autonomic systems might help. The section ends with a subsection describing the relevant background to building up a **Business Case** to give business evidence for the resource spend needed to implement an ARTS system.

[2] http://autonomicpowersystem.org.uk/

Section 4: *Human Factors* has been constructed to give a brief overview of the areas of concern of Working Group 4, interested in Human Factors, Human Interaction and Human Behaviour Change. Areas covered by this version include:

Travel Objectives/ Behavioral Responses: A focus here is on the current, hazy understanding of why and how people travel in the method they do, alongside the reasoning they adopt to carry out this task. To install change it is key to understand the mindset of the individual the change is aimed at. The key objectives uncovered within this research effort are around Time, Scheduling, Resourcing, Social Networks, Identities, Beliefs and Pleasure. In appreciation of the travel objectives, behavioural responses have been identified in the form of incentives that display the benefit an ARTS related system can potentially bring to a potential user. The incentives are all based around the travel objectives

Human Automation Interaction: Given the subject area, a consultation of the current literature around human automation interaction has been included in the study. Models such as the Technology Acceptance Model and the Theory of Planned Behaviour have been consulted in a bid to further strengthen the primary research of this study. To cohere with interaction, the study also looked at what kind of issues autonomic systems would provoke from users and how the differing perspectives could have an effect on an individual's travel.

Travel Information: In line with the EU FP7 SUNSET Project, the report set out a framework of information users would require in reducing car use. In adopting a more sustainable, efficient, smart city-esque mode of travelling, it was highlighted the areas of Feedback and Self Monitoring, Social Networks, Travel Information and Points and Rewards were the minimum categories that required attention to attain the above mentioned goal.

Future Work: Moving forward, the key focus discussed within the road map is based around collaboration and perspective. Collaboration in the sense that the various working groups are essentially working on different elements of the same problem space, in collaborating efficiently, the quality of the deliverable can be greatly increased.

Currently, the perspective and focus of this working group has been based on the European road space. In moving this knowledge space forward and to open up further research opportunities, an interesting focus would be to study different markets and users such as the Americas or the Middle East.