Development of a travel support system based on intelligent agent technology

Rafał Angryk
Center for Scientific Computing
University of Southern Mississippi
Hattiesburg, MS 39506-5106, USA
+1-601-266-4956; Rafal.Angryk@usm.edu

Krzysztof Kołodziej
Planning Support System Group, DUSP
Massachusetts Institute of Technology
Cambridge, MA 02139, USA
+1 617 722 0150; kwk@mit.edu

Iwona Fiedorowicz
Department of Information Management
University of Gdańsk
Gdańsk, Poland

Marcin Paprzycki, Maria Cobb, Dia Ali, Shahram Rahimi
Department of Computer Science and Statistics
University of Southern Mississippi
Hattiesburg, MS 39506-5106, USA
+1-601-266-4949; {firstname.lastname@usm.edu}

Abstract. The aim of our presentation will be to discuss the initial steps in the development of a tourist / traveler support system. This system is to use an intelligent agent technology to integrate various data sources into the geospatial database framework to address the needs of a traveler. While we are primarily concerned with a "roaming tourist" (and we will use this as a paradigmatic case) similar systems can be developed also to support other types of travel.

1 Introduction

Let us consider a traveler who is about to visit a particular geographical location. Such a person, depending on the purpose of the travel (e.g. vacation, convention, business), length of stay (e.g. one day, few days, extended stay), number of persons in the group and their interpersonal relations (e.g. single person, family, group of friends) may be interested in access to various types of travel related information. Obviously, the centerpiece of a travel support system will be the geographical information: maps, triptychs etc. Geospatial data will be used to provide information about the location of various objects (e.g. hotel, convention center, factory). However, even in a rather simple case of a short business trip, additional information, not readily available in the GIS systems may be desirable (e.g. location of Greek restaurants in the area). Obviously, such information may already be available on the Internet. However, using the Internet while outside of ones own office often means using unreliable and/or slow to very slow networks. This factor is especially important when, in addition to the textual and geospatial information, multimedia data is involved. Waiting for a photograph to be transferred over a modem only to find out that this photo does not contain information in which the traveler was really interested may be very annoying. In addition, when the number of search targets increases (e.g. due to the fact that the traveler has a rather eclectic set of preferences, or simply has trouble deciding what he or she would like to do) the time for searching for them increases as well. This results in the traveler potentially spending (wasting?) large amounts of time in searching the Internet and/or waiting for the results of the search to be displayed. A tourist who just checked into a hotel in San Diego, may not want to spend the next 3-4 hours searching the Internet for a place to eat in the evening and for attractions to visit the next day. She would rather prefer

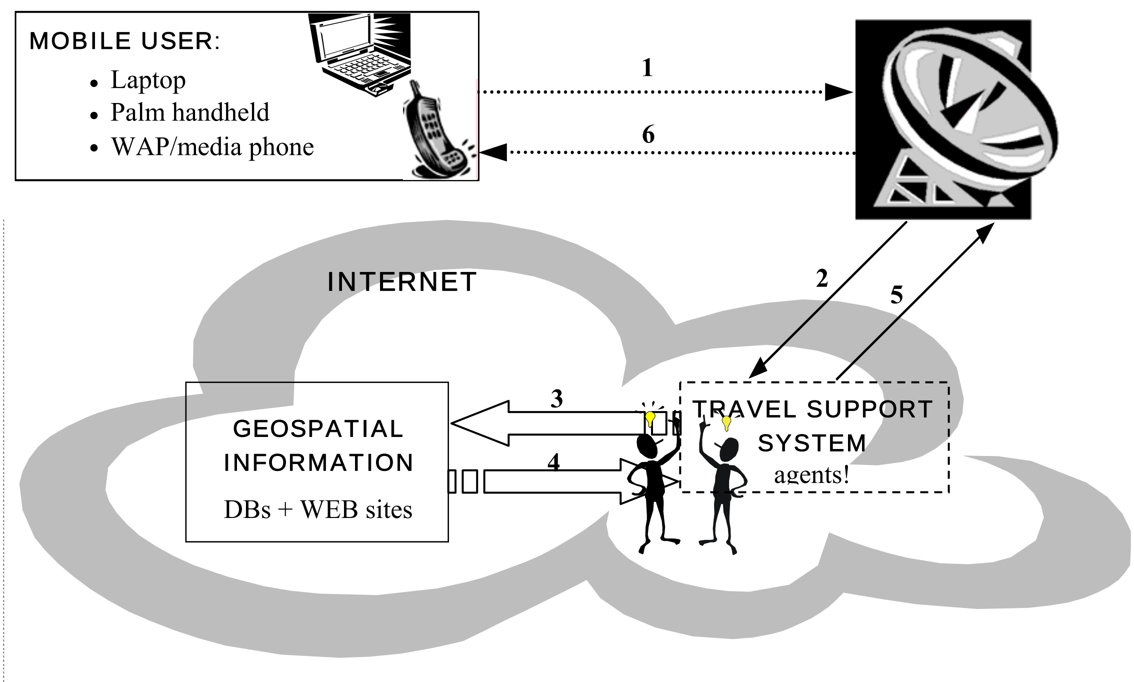
to go to the Mexican restaurant in La Jolla (information provided on the basis of the geographical proximity to the hotel location and restaurant type preferences) and enjoy a leisurely dinner followed by a stroll to a movie theatre in the Village (suggestion also made on the basis of geographical location of the restaurant and defined earlier entertainment preferences).
In the paper we will present the rationale and the proposed solution to the problem of supporting the needs of the traveler. We will describe how a system that integrates the GIS information as its core with the non-GIS travel-related information using intelligent agent technology can provide the needed functionality. We will then discuss in some detail the requirements that have to be put on each of the components of the system and their interaction.

2 General overview of the system

We believe that the technology already exists to develop a system that could support travelers in facilitating their needs and avoid at least some of the problems reported in the introduction. The proposed system is presented in Figure 1 and consists of:

a) GIS data, treated as the fundamental source for maps retrieval,
b) predefined databases and web-repositories on the Internet as additional non-GIS information sources,
c) intelligent agents system as a base to:
- search and filter information,
- cross-reference GIS and non-GIS information.

Figure 1. General sketch of the system



Arrows 1 and 2 in Figure 1 represent the mobile user's access to the travel support system. The traveler connects to her own Personal Agent for a short period of time allowing configuration of her actual requirements (dashed line symbolizes unstable networking). Solid arrows numbered 3 and 4 represent a data search and exchange performed by agents within the Internet. Gathered data is temporarily stored inside the system, waiting for the possibility of transportation to the user (arrows number 5 and 6).

3 Rationale

The proposed solution may, in some ways, seem resemble or redundant to the existing means of achieving similar goals, so we will first address some of these issues before proceeding with a more detailed architecture of the system. The first question that one may want to ask is: why not use locals (e.g. concierge at a hotel etc.) as the source of information? While we, as IT professionals, pride ourselves in developing software support for various activities, it is, at least for the time being, usually easier to communicate with another human being than with a computer. In addition, the tourist industry workers are usually quite well prepared to deal with the tourist requests. First, as it will be discussed in more details in the next paragraphs, the very selection of the hotel may be based on the information that is assumed is to be acquired upon arrival (which makes it a bit too late). Second, the information provided by the locals may be biased as it, in many ways, represents their personal preferences (instead of responding to the preferences of the traveler). Third, the particular, individual needs of a given traveler may require knowledge that is not easily available (or recognized as useful) and thus not popular among locals, e.g. information about the Polish restaurant or German delicatessen. It can be hoped that a prudent usage of the information available on the Web will be able to overcome these difficulties.

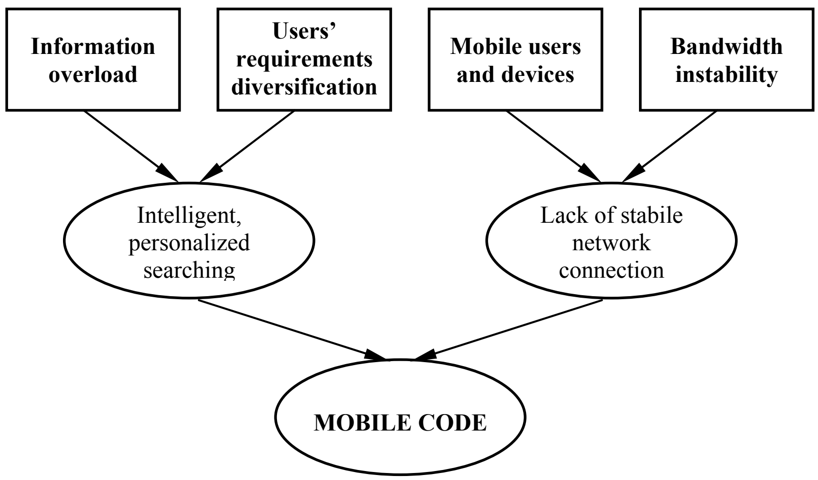
There exist a number of Internet-based travel services that provide various types of information to support the traveler. For instance, MapQuest can provide maps of various areas as well as Road Trip Planner, Traffic Reports and City Guides, including some basic locally available entertainment (movies and restaurants) [2]. Some of MapQuest's Services are available also on Palm VII™ Connected Organizers and Nokia Series 7100 Media Phones, taking advantage of the wireless devices [2][7]. Similarly on-line travel agencies (e.g. Travelocity, Expedia, etc.) provide travelers with hotel reservations as well as flights/cruises schedules and reservations or car rental possibilities [3][4]. And JunglePort offers big cities' maps, dining guides and yellow pages to download for the most of the Palm OS handholds [5]. Using the Palm™ Mobile Internet Kit in combination with a mobile phone or modem, this feature is available also for mobile users [6]. Finally, vast repositories of local information exist on the WWW in form of Web sites supported by various local organizations (e.g. chamber of commerce, local government etc.).

While recognizing the fact that all this information is available (and one could say that in case of someone searching the Web using a fast connection, there is a sense in which this data is "easily" available) a few points need to be made. First, some of the data may not be easily reachable from the point of view of the "number of clicks" necessary to find it. For instance, information if a given hotel has suites, or a sauna, or a restaurant, or full breakfast may require search of 3-4 levels deep for each hotel of interest. Considering that there may be 5-10 hotels in the area that a traveler may be willing to consider (e.g. due to their favorable price and location), this means that more than 40 clicks may be required to search all of them for the features that are of importance to a particular traveler. Second, not all information will be located in the same repository. While the hotel information fused with a limited mapping capacity is a relatively popular combination for large on-line travel agencies, information about other points of potential interest (e.g. museums, restaurants (especially smaller, niche, non-chain outlets), performing arts, or even movie theaters), is not available there. This means that the traveler would have to personally cross-reference the hotel and the remaining points of interest using a hard-copy map. Obviously, this type of activity is very likely to be extremely time consuming, especially when the final decision about the choice of the hotel depends, other factors (e.g. amenities, price) being equal, on the convenience of access to the other points of interest. Third, one has to consider that the individual preferences with regard to the interests can be extremely diversified. While for one person, the highlight of the travel is to be a visit to the opera, to someone else it may be finding a dance club, while to another person closeness to a golf course may be of extreme importance. Finally, one of the new characteristics of the support infrastructure for travelers is the usage of mobile devices. These devices are characterized by at least two important properties. Since they are used "on the road," at least for the time being, their usage very often involves low bandwidth Internet connectivity. In addition, they are usually characterized by a relatively short battery life, which introduces restrictions on their usage. All these together seem to indicate that an ideal travel support system should have the following features:

a) ***extensive/complete searches*** – available repositories, e.g. information provided by the on-line travel agencies and other repositories are searched for a complete (restricted only by resource limits) set of information pertinent to the needs of a given user,
b) ***cross referencing data existing in separate repositories*** while utilizing geospatial data as the basis for the cross referencing,
c) ***intelligence*** – the system is tuned to the needs of a given user, knows her preferences and uses them as a guideline for the search process that can proceed autonomously, without direct human supervision,
d) ***capability of work to be done off-line*** – to eliminate the need for the individual to be present while the search process takes place, more importantly, the traveler should not only not need to be present, but also not need to be logged on (and thus considerably reducing the power requirements of the system).

The above-mentioned four characteristics of the ideal travel support system point in the direction of agent technology as a framework of what may be used as the solution (for additional considerations refer to Figure 2).

Figure 2. The trends leading to a mobile agent based system idea [basing on [1]]



Let us now discuss the aforementioned features from the point of view of agent technology.

4 Agent technology as travel support system's framework

In a broad sense, mobile agents are programs that are capable to migrate autonomously to remote hosts and to perform there some activities on behalf of a user. After finishing their task on the server agents may migrate to the another location, terminate their own life or return to their mother's host [8]. To illustrate how well the agent technology matches the proposed features of the system, let us start from the last of above pointed system requirements.

Work off-line. One of the important features of the agent technology is that it provides perfect support for mobile computing. Since agents move the source of activity to the location of the data, the software system can be constructed in such a way that the data processing is initiated (i.e. agents are released) and the remote device can be shut down. This naturally matches with a need of a system based on cell phones, PDA's or laptop computers.

Intelligence. One of the important features stressed about the agent technology is that agent systems can exhibit a high degree of intelligent behavior [10]. As a matter of fact, this is one of the important reasons and contexts in which this technology is being considered [15],[16],[17]. This means that agent technology is a natural way of addressing the needs of the system that we propose, i.e. high level of personalization and intelligence in decision making.

Cross referencing. Cross-referencing data from multiple repositories (especially when the list of sources is not a'priori available, is a task that matches well with four features of mobile agents [9],[11],[12],[13]:

(1) mobility of agents – capability of an agent to travel between locations in search for information
(2) pure object mobility - ability of an agent to transfer objects through the network without requirement of agent traveling itself
(3) ability to create new agents and agents cloning – helping to search across a larger number of repositories concurrently
(4) collaborative effort – nowadays, the mobile agent technology research has moved from application of single agents to application of agent teams and the notion of a team matches well with the concept of cross-referencing.

Extensive searches. For the same reasons (1)-(4) that support cross-referencing, the breadth and depth of search are well supported by agent systems.

In addition we need to emphasize importance of ***agents' ability to act on behalf of the end user*** [9]. This future allows sending agents to the web hosts, which serve only registered users, without necessity of user's personal access to the Internet (i.e. knowing user's preferences an, agent can make reservation for tickets on cultural or sports events which are taking place close to the user's present location).

5 Related Work

Use of mobile agents increase dynamically. Nevertheless at present, only a few attempts at developing agent-based systems to support the needs of travelers have been developed. Typically, they concentrate their attention on the standard triplet airline-car-hotel [14] and are thus similar to the services offered by large on-line travel agencies.
In the analysis of intelligent agents [14] the authors presented three possible scenarios for mobile agents use in travel industry:

- A prospective traveler uses an intelligent agent as a searching service (extended with booking option) for travel tickets based on the user's personal preferences. A crucial part of the idea is necessity of all travel vendors to support the scenario and the level of user's trust in the agent's intelligence.
- Travel Agents adopt the intelligent agents for searching travel-related services among the vendors they do not represent already (i.e. looking for the cheapest way of transportation for their clients).
- Vendors of travel-related services (i.e. an airline and a car rental company) form an alliance and use mobile agents to provide their services as packages directly to final customers, omitting travel agents. In this model, a prospective traveler needs to find a site from which vendor's mobile agents are dispatched, provide his/her own travel requirements and start agent. The agent's job is to link customer's preferences to the correct package offered by alliance and deliver it to the traveler.

Scientists from Portugal [18] are currently working on a system of mobile agents, based on the German mobile agent system AgentSpace [19], that should be able to search and get data via Internet at remote SQL databases, on the bases of criteria defined in Java interface implemented on a mobile equipment type PDA (basing on the technology Psion 5mx and Nokia 9110 Communicator via GSM).
The very interesting research effort, going beyond the standard area, is described on the WWW site of ECRC, which presents the concept of *Mobile Service Agents* (MSA) [20]. The main idea of the system is to built mobile agents that are able to transport themselves through a network to serve locally connected users:

- providing to the users interactive access to data they already have
- serving as local representatives for remotely available services
- keeping and carrying tasks received from the temporarily disconnected users
- enabling dynamic mechanisms for changing (or updating) users' preferences among other user's agents

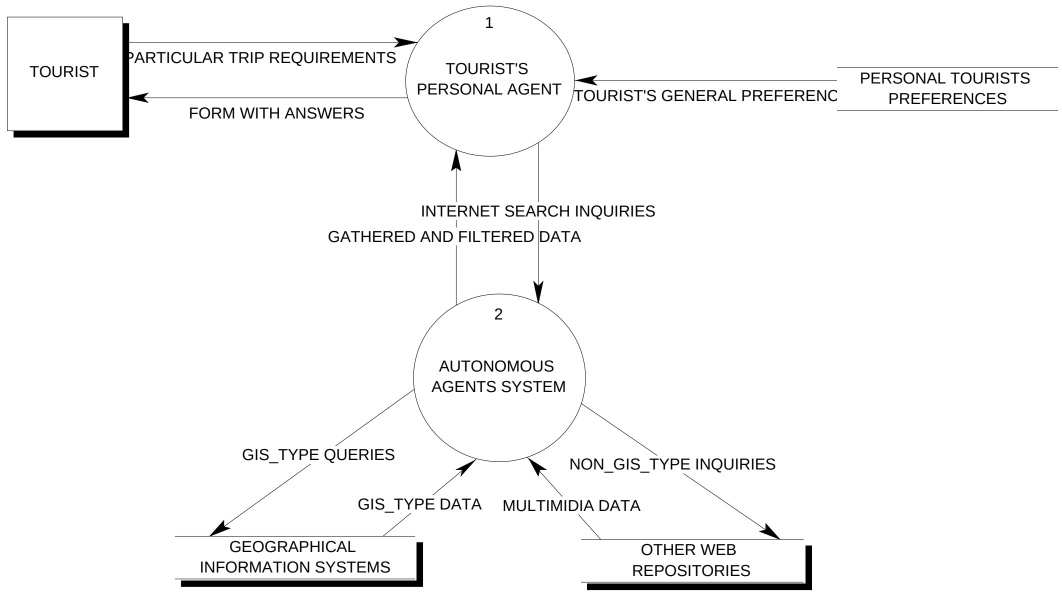
Unfortunately this page was for the last time updated in 1995 and our attempts to contact them were unsuccessful.

6 System architecture proposition

The proposed agent system will consist of two parts. First, there will be a number of pre-defined preferences (e.g. type of food, type of entertainment) divided into sub-categories etc. Second, these preferences will be cross-references with the travel-type categories e.g. for short business trips one typically needs only restaurants and hotels, while for vacation type trips one may be interested in galleries, or live entertainment. It will be assumed that for each individual user the system will modify and refine its capability to respond to the individual needs.

The traveler will contact her Personal Agent (Figure 3) and describe her present location and requirements and then disconnect from the system. On the basis of the contact and traveler's profile, the Personal Agent will generate search requirements reflecting traveler's needs. The real work will be started by Autonomous Search Agent(s) given the Internet search inquiries. After the search is done, the Autonomous Agent System will report the results to the Personal Agent and then discharge itself. It is the Personal Agent's responsibility to contact the user and transform the data to her mobile device. After that, the Agent can be suspended.

Figure 3. Context diagram of Travel Support System



The GIS data (maps etc.) will be the foundation of the system. It will be used as the reference framework for the other parts of the system. It will also be invoked in all cases when the information about reaching targets identified by the agents as "of (potential) interest" need to be displayed. The result will be a map and/or a triptych specifying how to reach these target points. For the purpose of the proposed presentation we do not plan to discuss a general situation of how multiple GIS resources are to be "integrated" and geographical data conflated. While such functionality in a system can be easily envisioned, this clearly goes beyond the scope of the proposed contribution.

In Figure 4, we present a more detailed picture of the proposed mobile agents system for traveler's support. We distinguished two kinds of mobile agents inside the Autonomous Agent System:

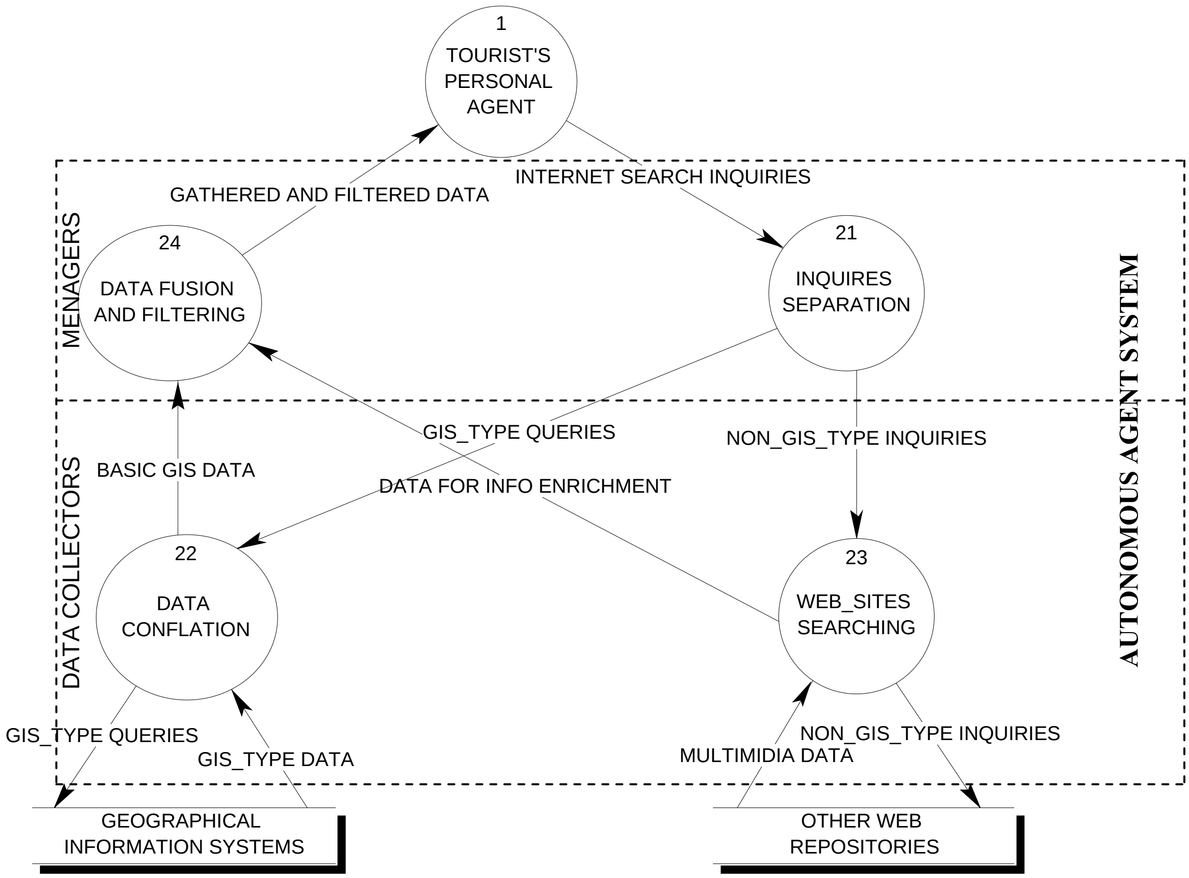
- Manager(s)
- Data Collectors

After receiving general type inquiries from a Personal Agent, a Manager needs to generate queries specific for GIS and for non-GIS repositories. These inquiries are taken by Data Collectors, whose main responsibility is to travel through the network looking for data. After searching, gathered data is carried by the Data Collectors back to the Manager, which starts performing data fusion and filtering. The Manager finishes Autonomous Agent System's work by sending filtered data to the Personal Agent. After that, the Autonomous Agent System suspends itself, waiting for search orders from another Personal Agent.

The Personal Agent contacts the Autonomous Agent System on behalf of the user and mobile user itself (ones to get orders from her, another time to submit the results). So, we can describe its mobility as not very strong, although it has to have implemented some intelligent features, which will be discussed later in this paper. This is totally in contrast with the Data Collectors behavior. They will be implemented as very light-weight agents with very strong mobility and cloning. Their main job will be to take queries from intelligent agents and perform data gathering (with cloning for speed-up).

Planning our system, we assumed that the Manager would also have the ability to clone itself. This feature should strongly increase searching process performance. Manager generating too many Data Collectors during a very intensive search may not be able to perform its other tasks, like gathered data fusion and filtering, efficiently because of received information overload. At the same time the Manager's cloning permits keeping track of searches already performed and keeps the Autonomous Agent System from the necessity of repeating the contact with the Personal Agent.

Figure 4. Data flow diagram for Autonomous Agent System



According to our considerations, processes numbered 1,21 and 24 require service by the agents that must contain some artificial intelligence mechanisms. For fulfilling tasks numbered 22 and 23, rather primitive, lightweight agents with strong transporting and cloning abilities would be more efficient. More detailed analysis of that matter will be presented at the end of this section, after more advanced presentation of the system itself (Table1).
In formal object-oriented programming terms, mobile agents can be defined as objects that have *behavior*, *state*, and *location*. A subset of behaviors possessed by every agent may slightly differ, depending of agent's server implementation, although mostly all of them support the following events [3]:

- Creation of an agent,
- Departure of an agent to another location,
- Arrival of an agent to remote host,
- Messages/Data exchange between agents,
- Messages/Data exchange between agent and another application,
- Destruction of an agent.

Providing our own maintenance for the above mentioned events, we are able to define our own autonomous mobile-agent based system. A more detailed description of our system functioning, presented in the form of a simplified state transition diagram, is included in Table 1.

Tab. 1. Maintenance for the particular events in agent's live.

TYPE OF AN AGENT	**Agent's Life Cycle**					
	Creation / Activation	**Departure**	**Arrival**	**Contact with other application**	**Contact with other agent**	**Discharge / Suspension**
Tourist's Personal Agent (PA)	1.Depart to the mobile user.	2.Store tourist's standard preferences from the server and remember the main server location. 5.Remember her localization and the type of the device she is using. 9.Temporarily store the copy of the gathered data on mother's server;carry the results to the user.	3.Contact mobile user's application. 6.Prepare inquiries for Autonomous Agent System; Contact MA. 10.Prepare the data in the form dependent on the mobile user's device type.	4.Take the requirements from the user; depart to the main server. 11.Report the search results; expect additional requirements; come back to the server and perform new task (5) or discharge (12).	7.Generate/Activate MA; submit general search inquires; wait for results. 8.Get data from MA and validate it; immediately depart to the mobile user.	12.Run garbage collector; discharge all MAs, which were generated/ activated; suspend itself waiting for server's orders.
Autonomous Managing Agent (MA)	1.Contact PA	3.Remember the PA's localization. 7. Carry the results to the PA.	4.Generate queries specific for GIS and for non-GIS repositories; generate/contact DC. 8. Submit results to PA; expect additional orders; come back to the server and perform new task (3) or discharge (9).		2. Take general inquires from PA; depart to another location (3) or generate/contact DCs locally (4). 5. Submit specific search inquires to DC; wait for results. 6. Get data from DC; perform data fusion and filtering; depart to the PA location.	9. Run garbage collector; discharge all DCs, which were generated/ activated; suspend itself waiting for PA orders.
Autonomous Data Collector (DT)	1. Contact MA	3.Remember the MA's localization. 6.Carry the data (4).	4. Contact local GIS or Web-repositories.	5.Start data searching/ retrieval; if satisfactory amount of data achieved report to MA (7) otherwise depart to another location (6).	2. Take specified by MA inquiries and start searching locally (4) or depart to another location (3). 7. Report carried data; expect additional orders; perform new task (2) or discharge itself (8).	8.Run garbage collector; suspend itself waiting for MA orders.

After obtaining information from the traveler, the Personal Agent will need to generate Internet search requirements (on the basis of the particular trip requirements and general tourist's preferences, which sometimes can be also in contradiction), for Autonomous Agent System. There is also a need to format these inquiries in the way most convenient for the Autonomous Agent System that has to interpret them and separate according to two different sub-types. Applying some genetic algorithms in the Personal Agent's body seems to be the most preferred choice. After each interaction with the user, the Personal Agent would be able to improve its image of the client's preferences, including also these ones which were not stated officially (i.e. traveler may always prefer hotels closer to park areas even if she will not openly formulate that). Some defuzzification of received information may be needed both for Traveler's Personal Agent and for Inquires Separation performed by the Autonomous Managing Agents [21],[22].
As presented above, the whole Autonomous Agent System will be built on the base of two kinds of mobile agents, one of which will perform the role of Manager(s) and others will work as Data Collectors. The Manager will be an agent with fuzzy logic mechanisms implemented. First of all, the Manager needs to separate the requirements for Internet Search received from the Personal Agent. An important fact is that the Autonomous Agent System can serve every Personal Agent, which requires its help for searching, so we cannot really assume that the Manager may know anything about the traveler's preferences. Using built-in inference mechanism, the Manager needs to be able to divide the data received from Personal Agents into GIS-type queries and non-GIS-type inquiries and than create Data Collectors to look for the data through the Internet.
In our future system the GIS data needs to be combined with the non-GIS information. Coming back to our example, let us assume that our traveler is interested in Polish restaurants in San Diego. He will be informed that there is one, but the information about the restaurant will be retrieved from individual Web-site setup by the restaurant's owner on some of the locally established server. A map of San Diego (i.e. retrieved from the yellow pages) with marked locations of the hotel and the restaurant needs to be made available for the traveler (as well as a triptych showing in detail how to get from the hotel to the restaurant will be prepared).
There are at least two ways of developing such a system. First, one can use only a limited number of predefined databases to access the non-GIS information. Second, the "entire" Internet can be used as the information source. While, in the first case, the resulting data may be considered more trust worthy although it may not be full, in the second case, more up-to-date but unreliable information can be obtained.
In both cases, the process of data fusion is a very challenging aspect of the system. It is not easy to take a digital geographic data from one Web-repository and combine it with data from a different source resulting in a single map of a compatible scale. Nevertheless, such mapping synergies were already successfully performed by GIS professionals from Webraska Mobile Technology in France [21], although that system, as well the one implemented in Japan [21], was mainly based on the first of the above proposed solutions. Hopefully, the situation of the lack of a standard mapping format will soon be improved thanks to the American industry group OpenGIS Consortium Inc. (OGC), which is currently working on the creation of the Web Mapping Server Specification (WMS) [21], which should allow geographic information to be fully available for automatic analysis.

7 Conclusions

In this paper, we have shown how existing mobile agent technology can be applied to the application of time saving personal travel assistant. The proposed architecture utilizes several classes of agents to create a traveler's preference profile, search for relevant data from spatial and non-spatial sources, and compile the recommendation. This system of autonomous agents that can be dispatched and run on client machines has great (time and energy) potential for travelers using mobile computing devices. We believe the work presented here is a natural extension to the currently available web-based travel sites, and we anticipate the development of a demonstration prototype in the near future.

References

[1] D. Kotz and R. S. Gray, *Mobile Agents and the Future of the Internet,* in Workshop: Mobile Agents in the Context of Competition and Cooperation (MAC3)" at Autonomous Agents '99, 1999. http://www.cs.dartmouth.edu/~dfk/papers/kotz:future2/

[2] http://www.mapquest.com/

[3] http://www.travelocity.co.uk/

[4] http://www.expedia.co.uk/

[5] http://www.jungleport.com/

[6] http://www.palm.com/software/mik/

[7] M. Matthews, *Nokia unveils new media phones for mobile internet access*, 2000. http://press.nokia.com/PR/199909/775931_5.html

[8] D B. Lange and Y. Aridor *Agent Transfer Protocol -- ATP/0.1,*1999. http://www.trl.ibm.com/aglets/atp/atp.htm

[9] B. Sommers *Agents: Not just for Bond anymore,* February 2001. http://www.javaworld.com/javaworld/jw-04-1997/jw-04-agents_p.html

[10] S. Rahimi, A. Ali, D. Ali, *An Investigation on Intelligent Software-Agent Technology*, to appear in Proceeding for IEMS and IC&IE 2001 joined international conference, Cocoa Beach, Florida, 2001

[11] D. Wong, N. Paciorek, T. Walsh, J. DiCelie, M. Young, B. Peet, Mitsubishi Electric ITA Horizon Systems Laboratory, *Concordia: An Infrastructure for Collaborating Mobile Agents,*1999. http://www.concordiaagents.com/MobileAgentConf_for_web.htm

[12] Mitsubishi Electric ITA, Horizon Systems Laboratory, *Mobile Agent Computing - A White Paper,* 1999. http://www.concordiaagents.com/MobileAgentsWhitePaper.html

[13] Objectspace Inc., *Voyager 4.0 ORB Professional Datasheet*, 2001. http://www.objectspace.com

[14] K. Heilmann, D. Kihanya, A. Light, P. Mousembwa, *Intelligent Agents: A Technology and Business Application Analysis*, 1995 http://www.ai.univie.ac.at/~paolo/lva/vu-sa/html/heilmann/

[15] J.Y.C. Pan, M.J. Tenenbaum, *An intelligent agent framework for enterprise integration*, in IEEE Transactions on Systems, Man, and Cybernetics, **21**(6), 1391-1408, 1991.

[16] W. Shen and D. H. Norrie, *Agent-Based Systems for Intelligent Manufacturing: A State-of-the-Art Survey,* in Knowledge and Information Systems, an International Journal, 1(2), 129-156, 1999. http://imsg.enme.ucalgary.ca/publication/abm.htm

[17] M. Wooldridge, N. Jennings, *Intelligent Agents: Theory and Practice*, in Knowledge Engineering Review, Volume 10 No 2, June 1995. http://www.elec.qmw.ac.uk/dai/pubs/KER95/

[18] http://cosmos.inesc.pt/~a07/index.html

[19] http://berlin.inesc.pt/agentspace/

[20] http://www.ecrc.de/research/dc/msa/

[21] A. Piegat, *Modelowanie i sterowanie rozmyte,* ISBN: 83-87674-14-1, Warszawa 1999.

[22] J. Korbicz, *Sztuczne sieci neuronowe. Podstawy i zastosowania*, ISBN: 83-7101-197-0, Warszawa 1994.