Towards Virtual Worlds and Augmented Realities: A Research Agenda

Christian S. Jensen[1], **Jan P. Nytun**[2], **Mikael Snaprud**[2]

[1] Department of Computer Science, Aalborg University
Fredrik Bajers Vej 7E, DK-9220 Aalborg Øst, Denmark, csj@cs.auc.dk
[2] Agder University College
Grooseveien 36, N-4876, Grimstad, Norway, Jan.P.Nytun@hia.no, Mikael.Snaprud@hia.no

Powerful drivers combine to enable the capture of reality in computers as well as the ubiquitous delivery of information content and services, based on the captured reality. We outline key drivers, exemplify application areas related to the research agenda, and describe briefly general software challenges as well as one specific data representation challenge to software technologies posed by the research agenda.

I. BACKGROUND

We are currently witnessing a number of important trends that serve as powerful drivers of advances in software technologies.

- Communication technologies improve rapidly. While the most revolutionary improvements may relate to wireless technologies, this also applies to wireline communication.
- We see rapid progress in sensor technologies. For example, the Smart Dust project at the University of California, Berkeley, aims to deliver autonomous sensing and communication in a cubic millimeter [1].
- The area of interaction technologies is experiencing many interesting developments. For example, diverse display technologies are emerging, e.g., map-like, foldable displays, digital "ink," eyepiece-based technologies, and technologies that project images directly onto the retina of the human eye.
- The trend towards miniaturization of computing technologies continues. Nanotechnology and molecular electronics promise to continue this trend.
- The performance/price ratio continues to improve for key computing technologies.

In the mid-1960s, Intel cofounder Gordon Moore predicted that processor performance would double every 18 months, a prediction that continues to hold true. For example, the number of transistors on a chip has increased more than 3,200 times, from 2,300 on the 4004 in 1971 to 7.5 million on recent the Pentium II processor. Storage and communication technologies, experience even faster rates of improvement.

In brief, these and other trends combine to promise the availability of a foundation for (i) capturing reality in computers with previously unparalleled fidelity and (ii) for the ubiquitous delivery of content and services derived from the reality in computers.

To exploit the abilities brought about by these trends, software technologies must meet a range of new challenges, and as such, these trends are drivers of software advancements. Some researchers have already embarked on projects that aim to meet some of the challenges. The investigators in the five-year "petabyte (10^{15} bytes, 200 petabytes equal all printed material) in your pocket" project, which recently was awarded USD 4.6M by the US National Science Foundation (NSF), predict that in 2015, for a few hundred dollars a year, everyone will have a personal petabyte database that can be accessed from any point [2]. Each such database will offer a personal, evolving, and customized view of all the on-line digital data that exists anywhere. To enable such databases, new software technologies must be invented that access tens of thousands of information sites and monitor possibly millions of rapidly changing content sources. The NSF also recently awarded approximately USD 5M to two related projects, concerning the real-time capture, management, and reconstruction of spatio-temporal events, and the foundations for a ubiquitous and universal information resource.

II. EXAMPLE APPLICATIONS

A. Virtual and Augmented Buildings

The envisioned research agenda aims to provide new technologies that will enable the creation of virtual and augmented buildings. Prior to the construction of a physical building, it becomes possible to view its virtual counterpart from diverse perspectives, e.g., that of an engineer designing the heating or the airflow, that of an architect experimenting with colors and wheelchair usability, and that of a plumber installing pipes. It becomes possible to monitor and analyze a wide variety of the properties of the building when it is subsequently being used. It also becomes possible to deliver content and services throughout the building.

B. Society-Level Application Integration

Today's companies spend a large amount of resources on the so-called enterprise application integration. Some estimates are that these spendings are 5 to 10 times larger than the purchase costs of new systems. When the problems faced by today's companies are scaled to the society level, when the number of on-line human users expands (e.g., in developing countries via initiatives such as the Simputer [3]), and when visionaries expect the Internet to reach billions of "gizmos" (via technologies such as Bluetooth at the outer reaches of the Internet) then the application integration challenges become very large. To increase the value of the services and the availability of data, interoperability will be important. The research agenda proposes solutions to some of the challenges.

C. Personalized, Location-Based Services

The envisioned research will provide foundations for developing services, delivered through the mobile Internet, that are customized to the user's personal preferences, the current situation, and the current location.

Many specific services may be envisioned. Today's streets are often loaded with advertisements, e.g., for cafés and stores. In the future, such offers, along with much more information, could be displayed on the mobile terminal of a pedestrian. Another possibility is for people to automatically exchange information through their terminals as they pass each other. As yet another possibility, users may record their movement "history", this will then allow them to find their way back to a desired location, e.g., a good restaurant. The paper's last section explores the data representation challenges inherent to this application area.

III. GENERAL SOFTWARE CHALLENGES

Software technologies must increasingly contend with continuous change. They must be able to manage huge amounts of diverse types of data. Computing infrastructures will increasingly consist of autonomous computing elements that must cooperate to accomplish tasks. Computing will be increasingly distributed, with the distributions changing rapidly. The diversity among computing elements will grow.

New technologies are needed that better support computing in such an environment. As but one simple example, how does one offer a user an adequate overview of a petabyte of data. Example areas where advances are needed include the modeling of process and structure, the management of process and structure under rapid change, the tracking and analysis of change, data reduction, and the delivery of content and services.

IV. DATA REPRESENTATION

In order to reuse data across location-based services (LBSs), an integrated representation, or data model, of all relevant geo-referenced content must be developed [4]. Such a data model will promote reuse of content and lower-level services when new services are developed. This will result in more rapid development of services as well as in higher-quality services, both of which are important to LBS providers who wish to maintain a competitive advantage. For example, certain services, such as location-based games, have a relatively short lifetime; new services must be made available quite frequently to retain the customer base.

To better appreciate the complexity of this challenge, it is instructive to learn that The Danish Road Directorate maintains more than 1000 attribute values for each cross section of each road in their database, which covers Denmark. A substantial fraction of these must be reflected in an integrated data model.

These attributes are quite specialized in that they are closely related to the roads themselves. They are merely the tip of the iceberg. In addition, the data model must capture the "real content," which is much more voluminous and open-ended. For example, such content includes information about stores, e.g., their opening hours, available inventory, and current sales, and about cultural events, e.g., the artists, attendance prices, and seat availability.

The model must also encompass one or more temporal dimensions, thus enabling the capture of data that describes the past, present, and future, as well as the capture of when data was entered into the model. Next, while most geo-referenced content is stationary or changes location only at discrete times, some content changes continuously. The locations of service users are prominent examples of the latter. Such content must also be captured. The data model must be conceptually simple and must also permit the provision of efficient services.

A. Euclidean Spaces, Obstacles, and Transportation Networks

Much initial work on query processing in relation to moving objects has assumed that the geo-referenced objects that queries concern live in a 1-, 2-, or 3-dimensional Euclidean space. Indeed, research based on this assumption may lead to results useful for some application contexts.

In other contexts, different assumptions may be more appropriate. Specifically, it is sometimes appropriate to expect some objects to constrain the locations of other objects. For example, the movement of joggers in a forest is constrained by fenced, private properties, etc. As another example, the movement of a ship is constrained by shallow water and land. Little research in query processing has taken into account such constraints on the movement and locations of objects.

These blocking objects do not reduce the dimensionality of the space in which the objects are embedded. In other application contexts, it is appropriate to constrain the locations of objects to a transportation network embedded in, typically, 2-dimensional Euclidean space. This in some sense reduces the dimensionality of the space available for movement—the term 1.5-dimensional space has been used. Examples abound. Cars typically move in transportation networks, and the destinations, e.g., private residences, hotels, and shops, may be given locations in the networks.

While some proposals for query processing techniques have taken into account the presence of transportation networks, many more opportunities exist for exploiting the presence of such networks in query processing. Put simply, better performing techniques may be developed when it is possible to constrain the movement of objects to a network, than when objects move more freely.

It should also be noted that Euclidean distances are often not of interest in this setting. Rather, techniques that apply to settings with obstacles or network-constrained objects will have to contend with other notions of distance. For some such notions, the distance between two stationary objects varies over time.

The kinds of queries one may expect also depend on the network more generally. Folklore has it that 80–90% of all automobile drivers move towards a destination. This suggests that drivers typically follow network paths that are known ahead of time. This statement may also lead one to assume that drivers have a particular interest in different properties pertaining to the path from their current location to their destination. They may want to know the remaining distance and the anticipated, remaining travel time. In this context, typical queries may not be simple range or nearest-neighbor queries.

B. Uncertainty

Location uncertainty is inherent to all or most geo-references of content and must be taken into account both in the representation and querying of the content. Object locations are sampled according to some specific protocol. As examples, the users may disclose their locations when they desire a service, they may supply their locations at regular intervals, or they may keep track of where the service thinks they are and then issue location samples to the service exactly when necessary for the service's record to be within a certain threshold of the actual location. In this latter example, the threshold is dependent on the specific service desired. Because location data are obtained via sampling, complete traces of the objects' movements are unavailable; rather, the service only knows the locations of the objects at discrete times.

Additionally, the samples themselves are imprecise. The sample imprecision is dependent on the technology used and the circumstances under which a specific technology is used. For example, the cellular infrastructure itself offers quite different precisions than do GPS and server-assisted GPS. The robustness also varies. In other words, the accuracy of the positioning is highly dependent on the user's location.

If a precise (but incorrect) trace is maintained for each user, queries may return sub-optimal results. On the other hand, if an overly imprecise record of the positions is kept, query results will also be sub-optimal. Maintaining a very accurate record of each user's trace will yield the best query results, but may lead to poor query performance. The envisioned data model for geo-referenced content must maintain a representation that is adequately precise and that does not adversely affect query performance.

REFERENCES

[1] Pister, K. "Smart Dust," `http://robotics.eecs.berkeley.edu/~pister/SmartDust/`.
[2] "A Petabyte in Your Pocket," `http://www.fastlane.nsf.gov/servlet/showaward?award=0086002`.
[3] "Simputer," `http://www.simputer.org/simputer/`.
[4] Jensen, C. S. and S. Šaltenis. "Data Representation and Indexing in Location-Enabled M-Services," NSF Workshop on Context Aware Mobile Database Management, RI, USA, January 2002.