# Deductive Response to Geographic Queries

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When we have a question, there may be many sources of information, including programs and data, relevant to finding the answer. We may not know which sources are appropriate. They may reside on different machines in diverse locations. Knowledge may be represented according to different frameworks, notations, or coordinate systems. The answer may not exist anywhere explicitly; it may need to be inferred, and it may depend on more than one source.

## Approach

We are pursuing a deductive approach to answering queries, using an automatic theorem prover to coordinate multiple knowledge sources. This approach exploits advances in automated deduction and program synthesis. Although it is independent of any particular domain, we have been applying it to answer geographic questions. An experimental system, called Geo-Logica, is being implemented to explore this approach.

A geospatial ontology and axiomatic theory are being formulated, which define and provide knowledge about fundamental geographical concepts. We employ the theorem prover not only to establish the validity of formulas expressed in the language of the geospatial theory, but also to extract answers to queries from the proofs it discovers. Knowledge sources are *procedurally attached* to certain symbols of the theory, so that the theorem prover behaves as if the knowledge of the source had been represented by axioms in the theory. A natural-language parser translates English sentences into the logical language of the geospatial theory. A three-dimensional terrain viewer has also been attached to the

theory, so that visual answers to queries can be displayed and explored as if in a flight simulator.

## Components

Geo-Logica uses the SRI theorem prover SNARK [SWC00] to perform the inferences for responding to queries. Under development for many years, SNARK is a first-order-logic automatic deduction system that is particularly well suited to perform inference in large axiomatic theories. In addition, it has built-in procedures for reasoning efficiently about regions in space and intervals in time. It has facilities for extracting answers from proofs and for attaching procedures to symbols, which we exploit heavily.

The geospatial ontology and theory of Geo-Logica describes properties of many fundamental geographical concepts, such as regions, latitude and longitude, distance, elevation, and a variety of geographical feature types, e.g., city, cave, or building. The theory was designed to accommodate the fact that the same place may have many names (Great Britain, United Kingdom), and the same name may refer to many places (Springfield).

Queries in English are parsed and translated into SNARK's logical form by Gemini [DGA+93], SRI's natural-language parser, which has been provided with a geographic vocabulary.

The external knowledge sources are connected to SNARK via SRI's Open Agent Architecture [MCM99], which allows us to procedurally attach websites, data bases, and procedures, regardless of their physical location or implementation language.

## Knowledge Sources

We have been experimenting with the following knowledge sources, most of which are procedurally attached to a symbol in the geospatial theory.

- The Alexandria Digital Library Gazetteer (`http://fat-albert.alexandria.ucsb.edu:8827/gazetteer/`) of the University of California at Santa Barbara, an index of the locations of more than four million places. For small places, the Gazetteer provides their latitude and longitude; for larger places, it provides their bounding box.

- The CIA World Factbook (http://www.cia.gov/cia/publications/factbook/), an online encyclopedia of the countries of the world, which provides their principal characteristics.

- A website at Northern Arizona University (http://jan.ucc.nau.edu/ cvm/ latlongdist.php) that computes the distance between two places, given their latitude and longitude.

- TerraVision [RLIB99], SRI's three dimensional terrain viewer, which provides a flight-simulator-like view of any specified location. TerraVision can also provide the approximate elevation of any place on Earth.

- A number of internal programs for converting between different notations, e.g., for latitude and longitude.

While the incorporation of new external knowledge sources is a time-consuming process, the DARPA Agent Markup Language (DAML, `http://www.daml.org`) program is now developing a language for annotating web pages and other online knowledge sources. Incorporating a DAML-annotated source will be much easier.

# Example

Suppose the system is given the task "Show the region 10 km south of the capital of Argentina." The phrase is translated into logical form by Gemini. The CIA World Factbook provides the information that the capital of Argentina is Buenos Aires. The Alexandria Digital Library provides the bounding box of Argentina. Also, searching within the bounding box, the ADL finds the latitude and longitude of Buenos Aires and confirms that it is in Argentina. An internal program, using a formula, computes the latitude and longitude of the place 10 kilometers south of Buenos Aires. TerraVision then displays a three-dimensional aerial view of that point (initially from a fixed altitude).

It would have been easy simply to write a program to perform that task; the point of this effort is to allow the theorem prover to figure out how the task is to be performed when no program has been provided in advance.

# Current and Future Capabilities

Other typical queries that can be handled by Geo-Logica include

> "Is Cuba north of Oman?"
>
> "Show a forest in Costa Rica." "Are there any others?"
>
> "How far is it from Lisbon, Portugal, to the capital of Brazil."
>
> "Show the place 100 km south of Buenos Aires, Argentina."

Although the natural-language capability is not yet up to it, Geo-Logica can handle the logical form of questions such as

> "Find a city and a state in Albania that have the same name."

We would like to extend the system to deal with preferences among answers, when there are more than one. For instance, the user might request

> "Show me the lake in Argentina with the highest elevation."

Eventually, finding multiple answers would be an occasion for Geo-Logica to initiate a dialogue with the user, to find out what his or her preferences are.

We would like to be able to superimpose (or at least juxtapose) TerraVision terrain views with other sorts of data displays, such as rainfall.

While the current system is timeless, we need to handle queries that include time and events as well as geological space, as in

"Over the last decade, at what time was rainfall highest in Napa Valley?"

We also should be able to have TerraVision display a movie showing changes in the terrain over time, or the effects of a particular event; this is of special interest for ecological modeling.

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## References

[DGA+93] John Dowding, J. Mark Gawron, Douglas Appelt, John Bear, Lynn Cherny, Robert Moore, and Douglas Moran. GEMINI: a natural language system for spoken-language understanding. In *Proceedings of the 31st Annual Meeting of the Association for Computational Linguistics*, pages 54–61, Ohio State University, Columbus, Ohio, 1993.

[MCM99] David L. Martin, Adam J. Cheyer, and Douglas B. Moran. The open agent architecture: A framework for building distributed software systems. *Applied Artificial Intelligence*, 13(1-2):91–128, January-March 1999.

[RLIB99] Martin. Reddy, Yvan. G. Leclerc, Lee. Iverson, and Nat. Bletter. TerraVision II: visualizing massive terrain databases in VRML. *IEEE Computer Graphics and Applications (Special Issue on VRML)*, 19(2):30–38, 1999.

[SWC00] Mark E. Stickel, Richard J. Waldinger, and Vinay K. Chaudhri. A guide to SNARK. Technical report, AI Center, SRI International, 333 Ravenswood Ave., Menlo Park, CA 94025, May 2000.