

Position-Annotated Photographs: A Geotemporal Web

The GTWeb system exploits the synergies of integrating different information appliances and publicly accessible databases to create and present trip diaries.

With the advent of digital cameras, photographs are no longer gathering dust, forgotten in old shoeboxes. Instead, they are lying unused in hard disk directories and on CDs. The Geotemporal Web system, belonging to the “capture and access” class of ubiquitous computing applications,¹ addresses this phenomenon by automatically converting raw data from the typical vacation trip into a lively Web site. Exploiting the synergies of integrating different consumer-grade information appliances and publicly accessible databases, a GTWeb site presents a trip overview, timelines, maps, and annotated photographs.

I first started working on GTWeb in the second half of 2001, in an effort to experiment with the presentation of GPS logs and digital photographs. Since then, I've been gradually adding features and maintaining its interfaces to keep up with technology evolution. Here, I discuss GTWeb's design and implementation and review what I've learned about integrating information appliances in general and presenting geotemporal data in particular.

Functional description

Initially constructing a Web site using GTWeb is fully automatic and involves integrating photographs from a consumer-grade digital camera, a track log recorded from a handheld GPS device,² and publicly accessible coastline, topog-

raphy, and gazetteer data. Once created, you can manually edit and further enhance GTWeb HTML pages.

A GTWeb homepage (see Figure 1) displays a description of the trip, such as (underlining denotes hyperlinks)

From 2.08 km S of Kastraki (hill) ([topological, street map](#)) (Sun Aug 19, 2001 10:48:55) to 1.74 km W of Metokhion Konstamonitou (populated place) ([topological, street map](#)) (Sat Aug 25, 2001 09:14:29) covering a travel distance of 898.02 km at an average speed of 60 km/h over an area of 45909 sq km. Duration 5 day(s), travel time 14:45 ([travel map](#)).

The homepage also includes links to detailed timelines, maps, and photograph galleries (all presented in chronological order); a trip overview on a topographical map substrate; and the trip's location on an azimuthal orthographic projection of the earth globe. (See Figure 2 for a UML diagram of the GTWeb content tree.)

The timelines list information such as when the traveler approached a geographical feature or took a photograph (see Figure 3). GTWeb divides the maps into separate pages based on when the trip was made and presents a separate overview map for each trip leg and detailed maps covering smaller areas. Each detailed map shows the route traveled and geographic features (populated places, streams, hills, and so forth), annotated with the time they were approached (see Figure 4). Each map is prefixed by a textual description of the trip part it illustrates, such as

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Figure 1. A personal GTWeb's overview page.

Detailed Trip Part Map 40°19'N, 23°42'E – 40°24'N, 23°59'E
 Wed Aug 22, 2001. From 2.96 km SW of Pirgadlikia (populated place) (topological, street map) (11:15:44) to 0.96 km S of Prosforiou (populated place) (topological, street map) (12:20:23) covering a travel distance of 46.99 km at an average speed of 43 km/h over an area of 237 sq km. Duration 01:04, travel time 01:04.

GTWeb indexes photographs using thumbprints and annotates them with a description of the time and place they were taken (see Figure 5). The same description, together with links to the corresponding trip leg map and detailed trip part map,

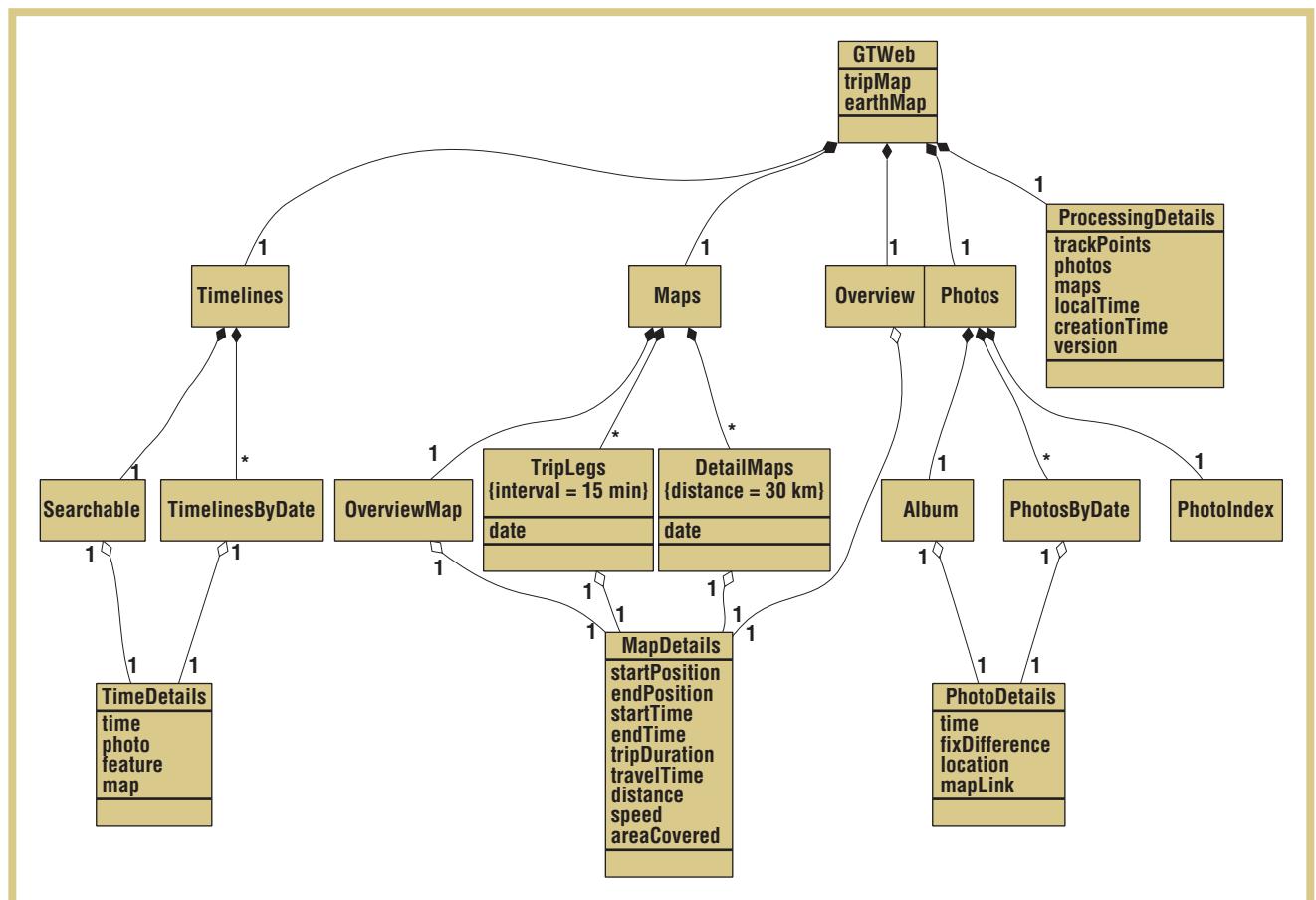
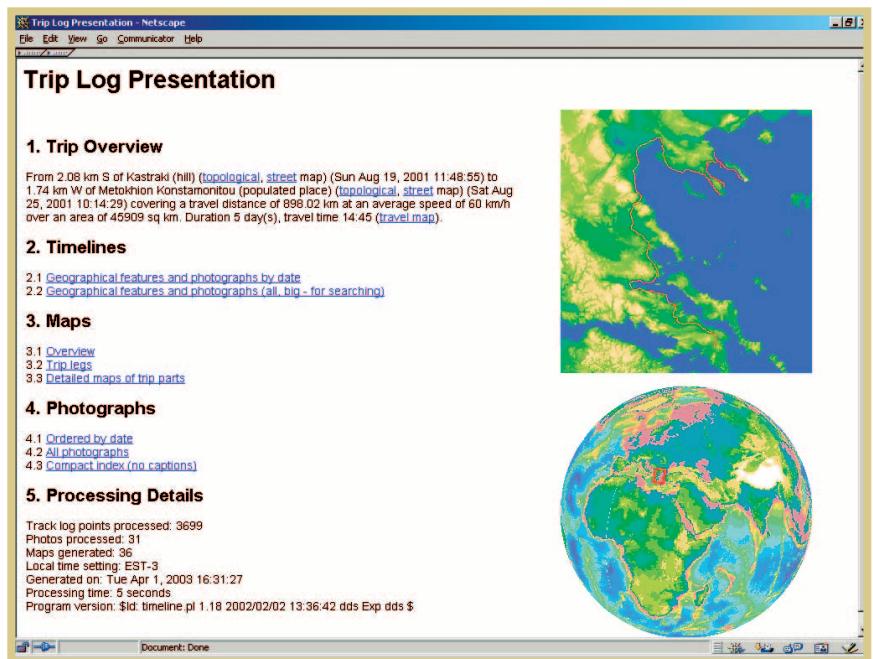


Figure 2. The GTWeb functional decomposition.

Wed Aug 22, 2001

- [12:51:29] Approached ([topological, street map](#)) 2.95 km SW of Megali Vigla (hill) ([topological, street map](#)) traveling at a speed of 18 km/h.
- [12:51:30] Photograph. About (most recent fix taken 1 seconds from the picture time) ([topological, street map](#)) 2.95 km SW of Megali Vigla (hill) ([topological, street map](#)) traveling at a speed of 18 km/h.
[...]
- [12:57:53] Approached ([topological, street map](#)) 2.73 km W of Thivais (populated place) ([topological, street map](#)) traveling at a speed of 17 km/h.
- [13:08:56] Photograph. About (most recent fix taken 5 seconds from the picture time) ([topological, street map](#)) 1.43 km SE of Thivais (populated place) ([topological, street map](#)) traveling at a speed of 18 km/h.
- [13:10:25] Approached ([topological, street map](#)) 1.52 km SW of Monoxilitai (populated place) ([topological, street map](#)) traveling at a speed of 18 km/h.
- [13:25:16] Approached ([topological, street map](#)) 5.48 km S of Moni Khiliandhariou (monastery) ([topological, street map](#)) traveling at a speed of 18 km/h.
[...]
- [13:40:00] Photograph. About (most recent fix taken 3 seconds from the picture time) ([topological, street map](#)) 0.39 km NW of Moni Xenofondos (monastery) ([topological, street map](#)) traveling at a speed of 19 km/h.

Figure 3. A sample GTWeb timeline
(underlining denotes hyperlinks).

also appears under the full-sized image of each photograph. All descriptions contain links leading to dynamically generated topographical and street maps available on public Web sites. (See www.spinellis.gr/gtweb/Chalkidiki for a sample GTWeb site.)

Application design

Figure 6 shows the dataflow diagram of the GTWeb creation process. The GTWeb software first processes a GPS track log together with the gazetteer database to annotate the track log with the nearest—in Euclidean distance—geographical features for each track point. GTWeb can then use topography (a grid of altitude points on the earth globe) and coastline data (closed polygons) to create the various maps. This phase superimposes the trip track and geographical features on the maps drawn by matching the respective longitude and latitude coordinates. Finally, GTWeb allocates the photographs into different maps, textually annotating them based on the time assigned by the respective appliance to each track log point and digital photograph. The availability of time information for both track log points and the photographs was the crucial factor that let me integrate the two different data sets.

Figure 7 depicts (as a UML diagram) the data model used to construct a GTWeb site. The primary types of data objects are

- Track points: latitude-longitude-time triples
- Photographs: the actual image plus an optional caption and the time each photograph was taken
- Gazetteer geographical features: coded references to each feature's geographical region, the feature's type (such as lake, town, or mountain), and the feature's name and coordinates

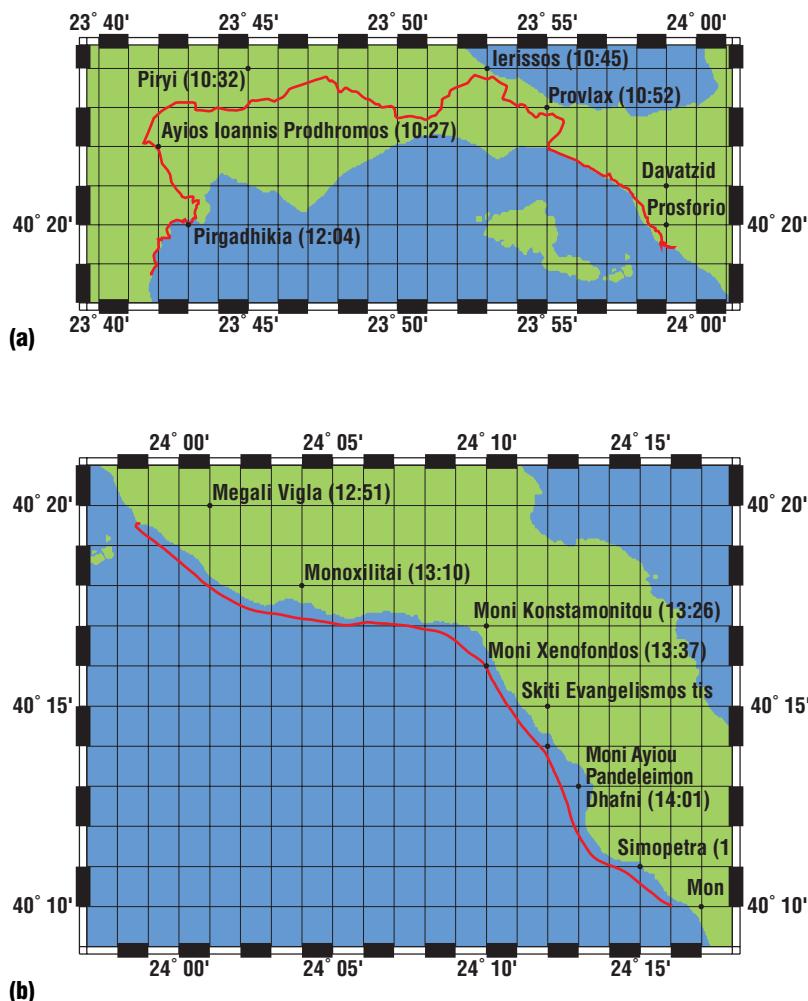


Figure 4. A detailed map of a trip leg over (a) land and (b) water.

Figure 5. Index of boat-trip photographs.

To create a GTWeb site, the system extends the three data objects by combining features of their parent classes:

- Annotated track points might contain the details of a geographical feature (for example, a town) near a given point, together with its distance.
- Annotated features refer to the time the user's track passed near them (the user "visited" them) and the track's nearest distance.
- Annotated photographs contain the details of the nearest geographical feature and track point, together with the time difference between the photograph and the temporary closest track point.

The track log point with the smallest Euclidean distance to the given feature determines the time and location of the traveler's visit to the vicinity of a given geographical feature. We can formalize this as follows:

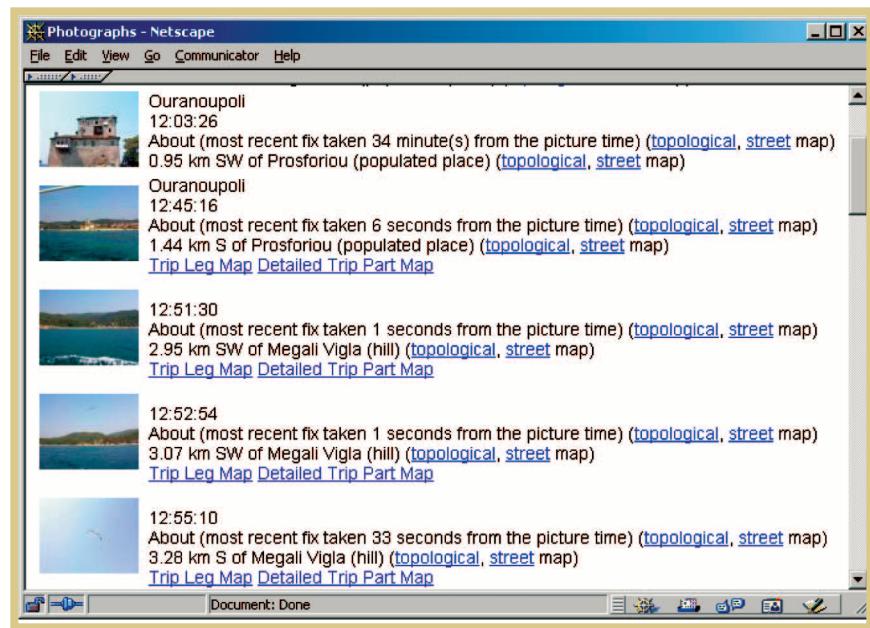
1. The coordinates of all known geographical features form a set F , and the coordinates of the track followed by the user form a set T .
2. Given two coordinate pairs (a_x, a_y) , and (b_x, b_y) , the notation $|a - b|$ denotes the Euclidean distance between a and b :

$$\sqrt{(a_x - b_x)^2 + (a_y - b_y)^2}.$$

GTWeb forms an annotated track log A by associating each track point t with its nearest feature f :

$$A = \{(t, f) \mid t \in T \wedge f \in F \wedge \forall f' \in F |t - f| \leq |t - f'|\}.$$

3. A set of "visits" V is formed from the annotated track log points that are nearest to each feature:



$$V = \{(t, f) \mid (t, f) \in A \wedge \forall (t', f') \in A |t - f| \leq |t' - f'|\}.$$

GTWeb uses most data in its native format, apart from photograph metadata where an intermediate program layer transforms file system resident information into XML, which is used for further processing. Thus, a photograph's details will appear as

```
<photo>
<name>DSC00007.JPG</name>
<time>998474606</time>
<caption>Ouranoupoli</caption>
<localtime>Wed Aug 22 13:03:26 2001</localtime>
<gmtime>Wed Aug 22 10:03:26 2001</gmtime>
</photo>
```

In a future version, I would probably use standardized schemas based on XML to

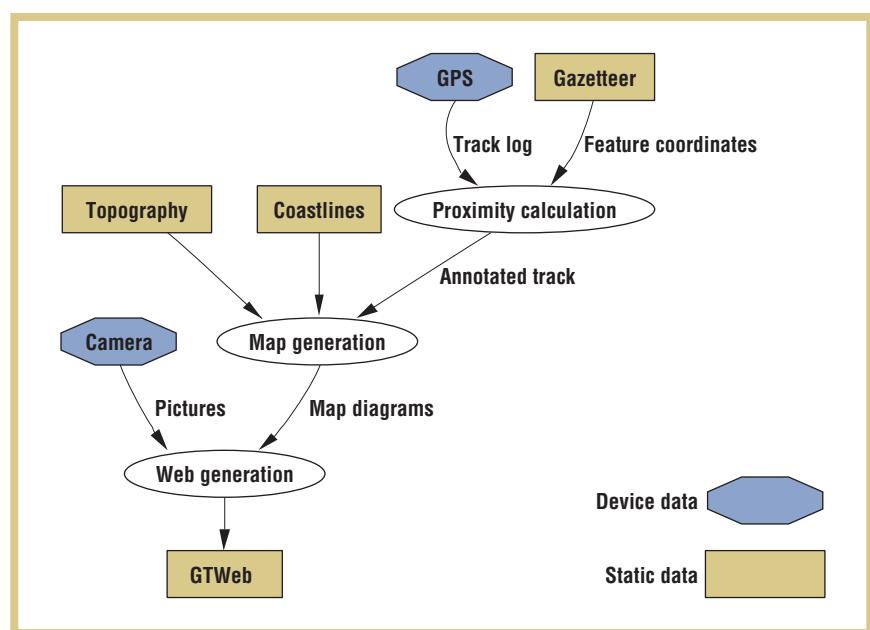


Figure 6. Data-flow diagram of the GTWeb generation process.

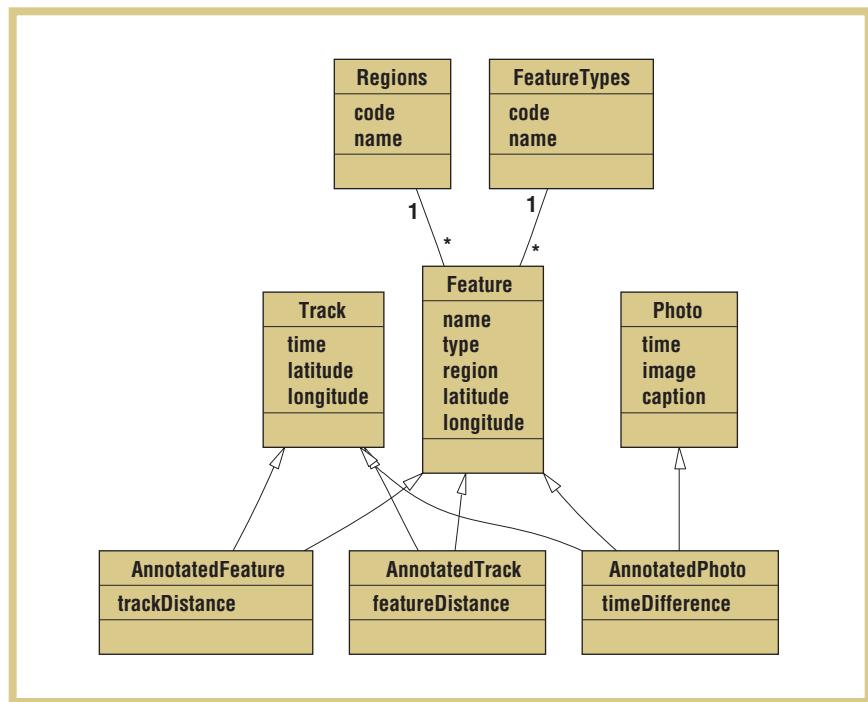


Figure 7. The GTWeb data model.

- The GMT coastline database
- The US National Geophysical Data Center five-minute earth topography (see <http://dbwww.escc.psu.edu/dbndx/tree/data/dem/etopo5.html>)
- The US National Geophysical Data Center global land one-kilometer base elevation model's digital terrain data (see www.ngdc.noaa.gov/seg/topo)
- The US National Imagery and Mapping Agency's GEOnet Names Server gazetteer (see www.nima.mil/gns/html/index.html)

I have used the system to illustrate several trips. In practice, it works well for summarizing relatively long (100 km) trips; shorter distances are less effectively presented owing to the lack of publicly available low-scale digital geographic data. This is also why I am currently not providing hyperlinks to photographs from the maps. GTWeb can correctly categorize and order photographs taken at the same location based on the time they were taken, but their geographic annotation will not be very informative. In the future, publicly available coordinate positions for elements such as monuments, town areas, road names, and other notable features could address this shortcoming. We could create a database of such feature details through community cooperative efforts by harvesting elements such as photograph captions. The current system is more useful for presenting car, plane, or boat trips than hiking or bicycle excursions.

interface with and access data, thus avoiding incompatibilities between different cameras and GPS devices. Similarly, at the physical level, you could probably standardize through uniform USB or Bluetooth device profiles the serial NMEA-based interface that I used for GPS data capture and the compact flash file system I used for transferring the photographs. (The National Marine Electronics Association defines the protocol for communicating with GPS receivers and other navigation aids.)

When selecting GTWeb presentation and implementation technologies, I had to choose among three different alternatives. A query-based interface presents results (maps, photographs) based on conditions the user specifies ("show me where I was on 17 August 2001"). Such an approach, however, is unsuitable for casual browsing, which I felt was a highly desirable feature. If I supplanted the query-based approach with a dynamic browsing interface, it would let users create content on the fly based on their actions; using this extended method, users could, for example, zoom and pan on the maps and photographs.

However, the drawback of both approaches is that they would depend at runtime on several large software applica-

tions such as a relational database, an application server, and a geographical information system. The complexity of these applications might be an inhibiting factor for adopting a system designed mainly for personal use. In addition, the platform's software and hardware requirements would introduce maintenance problems and create a significant preservation risk for material that would typically be archived for decades—who hasn't nostalgically browsed photo albums or diaries recorded 20 or 50 years ago?

The static HTML presentation format I selected for GTWeb is a lot more likely to survive a series of system upgrades over a period of 10 to 50 years than a perhaps more versatile system that would create content dynamically.^{3,4}

Implementation and use

The implementation of the GTWeb system relies heavily on several publicly available software packages and databases. Specifically, I used the GMT tools to draw the maps,⁵ the netpbm toolkit and Ghostscript to manipulate images, and the Perl language for composing the Web pages. Additionally, I obtained geographical information from

A small but irritating problem I encountered concerned the time synchronization of the two appliances I used. Correctly setting an appliance's clock is a task notoriously neglected; thus, when I needed correct time stamps to synchronize the digital camera's data with that of the GPS receiver, they were not always available. Time zones and daylight savings create additional challenges. Obviously, both appliances must be synchronized to use the same timeframe as a common reference. However, cameras typically operate

on local time, GPS devices on UTC time, and different PC operating systems on one or the other. Additionally, the system must generate meaningful captions and timelines, based not on the local time of the processing computer but on the local time that was in effect in the place where—and on the date when—the trip was made. Correctly handling and documenting this behavior is a problem that I never solved to my complete satisfaction.

Another important issue that will emerge once GTWeb sites are published on the Web concerns the creators' privacy. A GTWeb site might reveal more data and to more people than its publisher realizes. For example, authorities could deduce a speeding violation by examining a trip's timeline. Appropriate measures must be taken to distinguish the public Internet from an individual's or a family's intranet hosting personal experiences. The latter can be perhaps hosted on CD-ROM media never to be shared on the Internet. However, keep in mind that publishing and sharing the details of a trip is a time-honored tradition.

To investigate end-user views of GTWeb's presentation format, I conducted a small informal study by directing approximately 200 members of our academic community to view a sample trip report and fill in an online questionnaire. I had 30 responses, a 15 percent response rate. The (self-selected) population of my survey's respondents can be considered young with ages ranging from 18 to 35 years and an average age of 22 years. Their sex was roughly balanced (46 percent female, 53 percent male), as were their perceived IT skills: 13 percent considered themselves beginners, 66 percent reported they used computers with confidence, and 20 percent considered themselves experts.

When asked to compare GTWeb with other ways traditionally used to present photographs, 63 percent found GTWeb better than a paper-based album, while 83 percent found GTWeb better than a plain online photograph collection (26 percent and 13 percent, respectively, preferred the traditional presentations). Eighty percent found photograph captions to be interesting, while 16 percent found them useless

and 3 percent found them irritating. Eight-six percent of respondents found online maps to be interesting, while 6 percent found them useless and another 6 percent found them irritating. Finally, 83 percent answered in two separate questions that they would like to use GTWeb to present information about their trips and as the only way to present information about their trips. This figure dropped to 63 percent when asked whether they would like to use GTWeb to present their photograph collection, and to a meager 13 percent when asked whether they were likely to use GTWeb as the only way to present their photograph collection.

These figures, although not an outcome of a statistically rigorous study, indicate that GTWeb's strongest advantage is its

Lessons learned

Designing and implementing GTWeb taught me several important lessons regarding the presentation of trip diaries and integration of information appliances. (For related studies on personal navigation systems and location-based applications, see the "Related Work" sidebar.)

The informal survey I conducted showed that end users, although generally positive toward new ways of organizing, displaying, and disseminating digital photographs, are mostly interested in tools that let them effectively use the new data types generated by their appliances—in GTWeb's case, the trip log's coordinates. Designers of other applications dealing with novel data types, such as RFID tag data streams captured from consumer goods, will face sim-

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presentation of spatial data in the form of annotated maps. The organization of photographs, although not criticized, was mostly considered a "nice to have" feature that would probably be supplemented by additional dissemination forms such as photo albums, email, and (increasingly) multimedia messaging exchanges. In retrospect, I should have expected this finding, since digital photographs, offering most affordances of their paper-based relatives (and some additional ones), live and compete in an already rich ecosystem that has evolved over more than 150 years. Digital photographs can still be printed on paper and put in a traditional photo album or shown (using a TV instead of a slide projector) at a social gathering. In contrast, detailed spatial data in a form that GPS devices generate is a relatively new phenomenon. GPS receivers are gradually being added to consumer mobile electronics,⁶ but most people have no experience with using, presenting, or disseminating the data these devices generate.

ilar opportunities. For example, given a pervasive RFID deployment, the respective killer applications might let consumers optimize their shopping, investigate their spending or eating habits, organize their book library or CD collection, or receive advice on what to wear based on clothes worn in the past few days.

Additionally, standardization played a vital part in my endeavor. All topography elements, gazetteer information, coastline vectors, and the GPS track log were based on the same standard geodesic system (WGS-84), making it possible to superimpose and link elements acquired from the end-user device and different agencies on the same map. I could also download track log information from the GPS receiver using a common hardware interface and could access the photographs on the camera's storage device in a file system format that my workstation's operating system could recognize. Furthermore, I could download modular open-source software and public databases in their entirety, pro-

Related Work

Several researchers have examined personal navigation systems and location-based applications. James C. Spohrer has proposed the WorldBoard system for associating information with places on a global scale,¹ and Gerald Bieber and Martin Giersich describe using a PDA to aid the navigation in exhibition areas and fairs.² Mike Addlesee and his colleagues explain how sentient computing systems can change their behavior based on their environment.³

Past researchers have examined combining positional data with visual media as a way to augment existing geographical information systems.⁴ However, modern research, often performed within the wearable computing community,⁵ explores how to integrate data from *information appliances*^{6,7} such as digital cameras and GPS devices to empower human cognition and intelligence. Brian K. Smith and his colleagues examine using georeferenced photographs in an educational setting to investigate community change,⁸ and Jie Yang, Weiyi Yang, Matthias Denecke, and Alex Waibel theorize how to annotate tourist photos based on GPS-acquired information.⁹ Also, Neill Campbell, Henk L. Muller, and Cliff Randall have suggested using positional data to assist the user in photograph composition and the reconstruction of 3D images.¹⁰ In parallel, more recent research has examined using positional data to infer significant locations in a person's life,¹¹ and the automatic summarization of continuously acquired personal multimedia content.¹²

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viding me with facilities for annotating the photographs and displaying the track logs in a meaningful context.

Another important lesson from building the GTWeb system concerns the importance of what was, in effect, ancillary data for integrating two appliances. The two appliances I used tagged both the GPS track log and photographs with date and time information, which I exploited to link them together. I derived most of the value-added GTWeb content by joining (in the database sense of the word) data using as a join key approximate time or location matches. Making available all ancillary data, generated by many appliances, is likely to breed many innovative applications.

My low-end choices of technology were

also instructive. The content delivery mechanism I used (static Web pages)—although not sophisticated when compared to the various active-content technologies—proved surprisingly effective, portable, and resilient. Choosing consumer-grade appliances demonstrated that we can construct interesting pervasive computing applications by combining ordinary equipment in innovative ways. I thus exemplified the pervasive computing phenomenon that the whole is more than the sum of its parts,⁷ showing how combining digital photos with position information in the form of a GTWeb site adds value to both. In the near future, the provision of GPS ports^{8,9} and scripting extensions¹⁰ with digital cameras is making consumer photography inte-

grated with positional data ready for mainstream, letting us readily implement GTWeb-like systems using existing consumer-grade hardware.

I could enhance GTWeb in several ways. I could evaluate the information visualization following Cartwright and Hunter's waterfall process,¹¹ improving it along the lines suggested by the LifeLines work.¹² With the emergence of digital video recorders and cheap storage devices, I could also use GPS-derived positional data to annotate or caption video sequences. Additionally, I could further enhance GTWeb maps with hyperlinks leading directly to the relevant pho-

How to Reach Us

tographs, and I could use topology data to implement a 3D virtual tour following the original tracks.

Furthermore, I could integrate digital compass information (available on some GPS receivers) with the rest of the data to provide directional details about each photograph. Manufacturers could further enhance cameras to detect and record the camera's rotation and inclination for each photograph. I could then automatically annotate photographs containing three-angle rotational and lens setting metadata to mark interesting features or create image-based hyperlinks.

Given that the Web is primarily a communication medium, perhaps the most interesting enhancement would be a facility linking a GTWeb site with other people's GTWeb sites and similar cooperative endeavors such as the global confluence project (see www.confluence.org). For example, you could obtain a list of people who have visited the same place and link to their respective GTWeb sites. This last enhancement also relates to my survey's most interesting result: the perceived need to present and disseminate the spatial data we are increasingly generating. ▀

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