Levels of Detail in Descriptions and Depictions of Geographic Space

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Abstract

When navigating, people often rely upon a variety of geographic information sources to guide them to their destinations. These include maps, descriptions, or a combination of these as displayed traditionally on paper or through high-tech (handheld and in-vehicle) navigation devices. Maps provide a graphic representation of an environment and can vary in level of spatial (e.g., granularity) and labeling (e.g., label addition/removal) details. Likewise, written descriptions of an environment also vary in their levels of spatial (e.g., inclusion or exclusion of spatial information) and labeling (e.g., label addition/removal) detail. Importantly, experience within and memory for an environment may change as a function of these variations. The present experiments examine the interactions of spatial and labeling detail in generating and using mental representations of college campuses. The results of four experiments demonstrate that reducing spatial details through graphic generalization can increase memory for verbally-presented information. Results additionally demonstrate the importance of balancing spatial and verbal detail in maps and descriptions in correspondence with human working memory constraints. Accordingly, we present a limited model of appropriate spatial and verbal generalization strategies, with particular regard to implementation in geographical positioning devices.

Levels of Detail in Descriptions and Depictions of Geographic Space

Suppose you are unfamiliar with the Tufts University campus, and during a visit you wanted to find your way from Ballou Hall in the center of campus, to the Psychology Building on the Eastern edge of campus. Also suppose that Visitor Services provided you with a Personal Digital Assistant (PDA) equipped with navigational aid software including locational awareness, stored geographic campus information, stored verbal information about the campus and its layout, and a graphical and verbal interface. Given the PDA's limited screen size and the large amount of potentially displayable geographic information, what type of presentation would provide an appropriate combination of spatial and verbal details, such that human information processing limitations and the display of relevant information are balanced? Accordingly, Figure 1 demonstrates two possible levels of spatial and labeling detail, detailed in Figure 1a, and relatively sparse in 1b, both relating a route from Ballou Hall to Psychology.

One might expect that display 1a, because it contains more detail, may be the most effective way to present information, especially relative to display 1b. For the purposes of this example, we will call this *maximization.* However, there may be costs associated with information density – specifically, limitations of the human information processing system may result in reduced knowledge acquisition with maximized detail compared to relatively impoverished displays (Baddeley, 1992; Mayer, 1997; Schneider & Taylor, 1999; Sweller, 1988). Indeed, work investigating the effects of dense information in navigation displays finds that generalization provides overall usability and utility improvements (Agrawala & Stolte, 2001; Tomko & Winter, 2006). As a result, there might be a motivation to dramatically limit spatial and verbal information to avoid potential usability and cognitive costs. We will call this motivation to limit information *minimization.* However, limiting spatial and verbal detail may also carry cognitive costs, brought about in part by ambiguities inherent in sparse information (Mani & Johnson-Laird, 1982; Schneider & Taylor, 1999). The present experiments are designed to determine the interaction, and the appropriate combination, of spatial and verbal content to help a person learn about a campus environment – that is, we compare levels of detail in an effort to leverage human information processing capabilities while still taking into consideration potential limitations in display resolution and data capacity of spatially-enabled handheld personal digital assistants (PDAs). Note that verbal content on maps is typically found in the form of labels or landmark descriptors (e.g., historical or functional details); the present work examines the former. Verbal content may also be found in spatial descriptions (e.g., verbal directions for navigation purposes), which will be examined in Pilot Experiment 2 and Experiment 2 proper. Two primary and largely distinct research areas contribute to the present experimental motivations and hypotheses, that of geographic information systems and its examination of detail and granularity, and that of single- and multi-format representations and their relationship to spatial cognition, working memory theory, and multimedia design.

Level of Detail and Granularity

In this work we are concerned with appropriate mixes of detail in graphical and verbal representations of spatial information. Any representation of the world has at its heart a *granular partition*, which is a collection of grain cells that defines the precision at which entities and relationships in the world can be represented. Level of detail can be related to granularity, resulting from the application of an *indistinguishability relation*. A major general discussion is that of Hobbs (1985), framed in the language of logic, where an indistinguishability relation is defined on the domain, where two entities are *indistinguishable* if no relevant element of the representation distinguishes them. For example, two campus buildings may be indistinguishable in a graphical representation if they are drawn using a single polygon, and indistinguishable in a textual representation if they are given the same overall label (e.g., Administrative Buildings). The hard problem is to determine those elements that should be distinguished in the graphical and/or the verbal representation, to make the information accessible to the user. Of course, this issue is dependent on the particular user, the user's purpose in requiring the information, and the information device. For example, a greater level of graphical and textual information can be provided by a laptop as opposed to a small handheld device, but this may be supplemented by a greater level of detail of verbally represented information provided by audio cues, such as in an in-car navigation system.

Figure 2 shows diagrammatically the interplay between levels of detail in a bimodal verbal and graphical representation of geographic information. Finding the appropriate combinations of levels of details is the topic explored in the experiments described herein. Changing the level of detail may be accomplished by:

- Graphic generalization, for the depictive representation
- Textual/verbal summarization, for the descriptive representation
- Cartographic generalization, for the combined text-graphic representation.

Changes in graphic level of detail, especially minimizing available information, may produce representations that lack key features to truly accomplish a given task –

such as when faced with a detour or change of venue. Additionally, graphic generalization procedures often introduce ambiguities, which have cognitive consequences (Mani & Johnson-Laird, 1982; Schneider & Taylor, 1999). Conversely, maximizing graphical details can also lead to cognitive difficulties, such as longer search times and decreased memory (Florence & Geiselman, 1986; Mayer, 2001). The general consensus, however, appears to support better cognitive processing through simplification (and not oversimplification) of graphical displays (e.g., Kaplan, Kaplan, & Deardorff, 1974; Tufte, 1983).

Verbal and graphical level of detail

The cognitive effects of single-format verbal representations of space, particularly as they relate to graphical representations, have also received attention in the spatial cognition literature (Mani & Maybury, 1999; Perrig & Kintsch, 1985; Sparck-Jones, 1993, 1999; Taylor & Tversky, 1992a, 1992b). According to this work, spatial descriptions are fundamentally different from graphical depictions in several ways; first, descriptions provide an additional level of abstraction, by requiring that any derived mental representations must be interpreted from language. Also, greater need for interpretation during description reading often eventuates in more errors in the resultant mental representations. Despite these challenges, people can accurately represent, and make inferences about, spatial information acquired from descriptions (Taylor & Tversky, 1992b). Analogous to cartographic generalization, spatial descriptions can be subjected to textual summarization, resulting in a lower detail level as a result of selectively presenting and generalizing important content (Sparck-Jones, 1997, 1999). In the case of a college campus, for example, a generalized description could eliminate irrelevant (to the task) building labels, and/or reduce the described spatial detail associated with relatively unimportant (again to the task) campus regions.

More common than single-format spatial representations, perhaps, are multi-format ones. For example, in the simplest form would be maps with textual labels, as in Figure 3, and increasing in complexity textual descriptions accompanying maps (e.g., describing the function of a particular building), such as may be commonly seen in tour guides. Relative to single-format graphical representations, there is evidence that multi-format interfaces are preferred by users, and that they are more effective when implemented within geographic devices (Cohen, Johnston, McGee, Oviatt, Clow, & Smith, 1998; Wauchope, 1996). Well-designed geographic interfaces effectively balance the graphical and verbal information to produce easily understood, concise, and cognitively effective (i.e., search times, memory for information) information displays.

In each case, changing the level of detail requires a modification of the indistinguishability relation. This modification may be achieved in two general ways. The first is the process of *selection,* where specific content is either omitted or displayed. This is equivalent to changing the domain or range of the relation. The second is the process of *amalgamation,* where content may be combined or separated. This changes the injective quality of the relation. These processes are formally analyzed by Stell and Worboys (1998). In the experiments described below, the consequence of variations in these parameters is investigated.

A review of research devoted to the interaction of spatial and verbal elements in learning from multimedia systems is described in the following section. Little work, however, has directly examined systematic manipulations of spatial and verbal levels of detail, and how such manipulations may affect resultant spatial mental representations. A second goal of the present research, therefore, is to develop and test the cognitive effects of a verbal analog to cartographic generalization, particularly as it may interact with varying levels of spatial detail.

Multimedia Design Principles and Working Memory

In the present context, multimedia is defined as the combination of two or more information formats or modalities within a single (spatially and temporally contiguous) presentation. In its simplest form, multimedia combine labels with images, such as commonly found on campus maps (e.g., Figure 3); relatively complex multimedia forms include combinations such as text with animation, or narration with video. This level of geographic multimedia is not uncommonly seen in travel guides and software. Multimedia presentations have long been cited as effective learning mediums, particularly relative to single-format presentations (e.g., Allen, 1967, 1971; Peeck, 1994). Multimedia learning advantages are especially pronounced when highly relevant images accompany texts (Levie & Lentz, 1982), and when the two formats occur close in time and space (see Mayer, 2001 for a review of multimedia design principles). While the majority of multimedia research examines the learning effectiveness of complementing texts with images, the converse is relatively under-researched (Brunyé, Taylor, Spiro, & Rapp, 2006; Gyselinck, Cornoldi, DuBois, De Beni, & Ehrlich, 2002; Stone & Glock, 1981); that is, complementing stand-alone images with text, such as commonly seen when labels or short descriptions are placed on maps. Thus, the cognitive impact of systematic variation in labeling and/or graphic detail on maps (or in spatial descriptions) has not been determined. Additionally, the majority of multimedia research has focused on declarative (e.g., textbook learning) and procedural (e.g., toy assembly sequences) learning, and has not been extended to geographical spatial information.

Recent work by educational and cognitive psychologists has focused on determining the working memory mechanisms responsible for multimedia learning advantages (e.g., Brunyé, Taylor, Rapp, & Spiro, 2006; Mayer, 1997). Towards this goal, Mayer (1997) proposed the *Generative Theory of Multimedia Learning*, integrating dual coding (Paivio, 1986) and generative theory (e.g., Soraci, Franks, Bransford, Chechile, Belli, Carr, & Carlin, 1994; Wittrock, 1989) in an effort to provide a cognitive account for learning advantages seen with multimedia. According to Paivio's (1986) *Dual-coding Theory*, verbal and image processing occur both separately and concurrently, and information encoded in both formats is better-retrieved from memory compared to single-format information. *Generative Theory* proposes that active knowledge acquisition, such as seen with the process of actively selecting (single- or multi-format) information within working memory, results in memory advantages in comparison to relatively passive processing (e.g., Soraci, Franks, Bransford, Chechile, Belli, Carr, & Carlin, 1994; Wittrock, 1989). Mayer's (1997) theory posits that the simultaneous processing of texts and images, and active selection of components from these presentations, are the two primary contributors to multimedia learning advantages. This theory has received repeated empirical supported in the context of both educational (Glenberg & Langston, 1992; Mayer, 1989; Mayer & Gallini, 1990; Mayer, Bove, Bryman, Mars, & Tapangco, 1996; Peeck & Jans, 1987; Stone & Glock, 1981) and cognitive psychology (Brunyé et al., 2006; Gyselinck & Tardieu, 1994; Gyselinck et al., 2002).

Critical to the present experiments, multimedia research has demonstrated both advantages and disadvantages to increasing or decreasing verbal and spatial detail. With increased detail, even in the context of multiple-presentation formats, cognitive load increases; that is, there is a point of diminishing returns with increasing informational content. This notion is supported by demonstrations that working memory is limited in the information it can contain simultaneously (Baddeley, 1992; Sweller, 1988), and that memory benefits from removing extraneous or irrelevant details (e.g., Garner, Gillingham, & White, 1989; Levie & Lentz, 1982). *Cognitive Load Theory* (Sweller, 1988) proposes that learning materials should be structured to reduce working memory load, providing learners with the opportunity to acquire mental models, or schemas, within which new information can be easily integrated. The most extreme form of load reduction would be removing all content that is presumed unnecessary. There are obvious drawbacks to this method when someone relying on a map or spatial description must change destinations, or make a detour. Spatially-enabled PDAs may offer a solution to this problem by offering varying levels of detail that are easily manipulated by the user.

The overall goal of the present experiments, therefore, is to 1) determine overall effects of systematically varying graphic and labeling detail when conveying information about an environment on use and memory for an environment so as to 2) identify design principles for combining textual and graphic presentations that balance the capabilities and limitations of human working memory so that spatial information can be well-learned and readily retrievable from memory.

Experiments and Hypotheses

The present experiments are designed to help develop principles for useful geographical interface design and development, such that they display information in a manner that leverages:

1. Existing cartographic and textual generalization principles
2. The learning advantages of multi-format multimedia presentations, and the corresponding multimedia design principles
3. The implications of cognitive load on information acquisition, particularly as they apply to multi-format learning

With these in mind, we present a series of experiments to examine the cognitive effects of varying levels of verbal and graphical detail in maps and spatial descriptions. The first two experiments (Pilot Experiment 1 and Experiment 1) examine varying levels of verbal and graphical detail in maps, using map drawing and description writing as dependent measures, respectively; the latter two (Pilot Experiment 2 and Experiment 2) adapt these variations to spatial descriptions, again using map drawing and description writing as dependent measures in Pilot Experiment 2, and map drawing alone in Experiment 2.

Pilot Experiment 1

This pilot experiment was designed to test whether changes in verbal and spatial levels of detail are substantial enough to increase rates of requested information as provided information decreases through level of detail variations. That is, will decreases in spatial and verbal detail on maps lead to corresponding increases in requests for information? Further, do decreases in graphic and labeling detail similarly affect such requests?

To this end, participants studied three maps and then listed any supplemental information they would like to have in addition to what each map provided. We predicted that reductions in graphic detail through generalization would lead to increases in requests for spatial (but not verbal) information; for example, increased requests for building perimeter information. In contrast, reductions in labeling detail would lead to increases in requests for verbal (but not spatial) information; for example, increased requests for key locations (e.g., registrar, campus security), and street names. Requests for non-manipulated or overall non-included details however, should remain consistent across levels of spatial and verbal detail; for example, requests for local transportation information, entertainment options, canonical reference system, and parking locations. If these hypotheses are supported, it would demonstrate that our manipulation is phenomenologically noticeable; that is, powerful enough to produce substantial differences in the way participants view (and potentially use) spatial and verbal information as displayed on maps.

Method

Participants and Design. Thirty Tufts University undergraduates participated for partial course credit. Half studied spatially generalized maps, and the remaining half studied spatially detailed maps. Each group studied three maps in counterbalanced succession, one with full, one with important, and one with no labeling detail. We therefore incorporated a mixed design, with graphic detail as a between-participants factor (2 levels: detailed, generalized), and labeling detail as a within-participants factor (3 levels: full detail, important detail, no detail).

Materials and Apparatus. To serve as stimuli, we needed a set of maps that would be: 1) tractable in an experimental paradigm, making it possible for participants to learn several maps during one experimental session, 2) amenable to cartographic and textual generalization, 3) practical, in that participants are likely to encounter maps of these kinds outside of the laboratory, and 4) likely unfamiliar to Tufts students. With these criteria in mind, we based our maps on those of three college campuses: Beloit College, St. Olaf's College, and Grinnell College, all small mid-Western colleges. Each campus map was modified to fit the following criteria: 1) no more than 59 and no less than 53 buildings (Grinnell 53; Beloit 59; St. Olaf's 54), 2) exactly 9 roads, and 3) all buildings can be placed into one of five categories (Academic, Administrative, Athletic, Residence, Theater/Arts). Beloit and Grinnell maps were vertically elongated rectangles, and the St. Olaf's map was a horizontally elongated oval. Figure 3 depicts the Beloit College map, modified to fit the above criteria.

Six versions of each campus map were produced, two levels of spatial detail, and three levels of verbal detail, for a total of 18 maps. Spatial generalization used elements of established cartographic generalization procedures (McMaster & Shea, 1992); two detail levels were produced, spatially detailed and spatially generalized. The spatially detailed maps depicted precise building and category perimeters, and walking paths (e.g., Figure 3), while spatially generalized maps grouped buildings by space (outer perimeter boundaries) and category (high frequency membership) (e.g., Figure 4). Verbal generalization was done by producing three detail levels, full labels, important labels, and no labels. Full labeling showed labels for every building and road, important labeling showed labels for all roads, and buildings determined to be of primary interest during a campus tour, and no labeling excluded all labels (aside from category legend). Important labels were determined through a pilot experiment in which 8 undergraduates wrote down the buildings they would be most interested in seeing during a college campus tour. The top 12 requests (e.g., library, admissions office, and arena/stadium) were included on important verbal detail maps.

All maps were presented in succession, one map at a time, on a sheet of 8.5” x 11” white paper, printed in color (black 12-point Times New Roman font, colored categories, black road outlines, and grey path outlines). The dependent measure was administered on a blank sheet of paper with brief instructions outlining the task of writing down requests for supplemental information. Specifically, participants were instructed to write down what additional information they would like for a campus tour, to make it more informative and enjoyable.

Procedure. Participants were randomly assigned to one of two graphic detail groups (detailed or generalized) for the entire session, and asked to study campus maps with the intention of using them as guides for a hypothetical campus tour. Each participant sat at a desk and studied a map for 5 minutes. The map was then taken away, and they were given 10 minutes to write down supplemental information requests. This procedure then repeated for the remaining maps. The order participants received the levels of labeling detail was counterbalanced across participants.

Results

Scoring. Written requests for additional information were scored by placing each request into one of thirteen categories (building names, street names, building perimeters, dining, entertainment, housing, key locales, landscape, map features, parking, scale, services, and transportation). Examples of specific requests for each category are as follows: building names: “what were the names of the residential buildings east of College St.?”; street names: “what are the names of the streets that enter campus from the southwest?”; building perimeters: “is that just one big building, or a group of buildings?”; dining: “where are the dining halls?”; entertainment: “where can I go bowling?”; housing: “where are freshman dorms?”; key locales: “where is the synagogue?”; landscape: “are there any hills on campus, or is it all flat?”; map features: “can the map be larger?”; parking: “where can visitors park?”; scale: “how far is it from one end of campus to the other?”; services: “is there an ATM on campus?”; and transportation: “is there a bus to get around campus, if so, where does it stop?” Each category frequency was collapsed across campuses, and totaled for each of the 6 map types (graphically detailed, generalized; labeling detailed, important, none). These categories were then classified into spatial, verbal, and general request types. Spatial requests included the building perimeter category, verbal requests included building names and street names. Finally, general requests contained the remaining ten categories – dining, housing, key locales, map features, parking, scale, services, and transportation.

Analysis. Each of the thirteen categories was analyzed using the repeated measures Analysis of Variance (ANOVA), with graphic detail as a between-participants factor and labeling detail as a within-participants factor. Each participant’s supplemental request frequency was converted to a proportion by dividing by the total number of requests across all categories (i.e., relative frequency), then submitted to arcsine transformation (i.e., Feller, 1957; Kirk, 1968). Note that all tabulated and graphed data show proportion values prior to arcsine transformation for interpretability. All planned comparisons used t-tests with Bonferroni correction for multiple comparisons. See Table 1 for a summary of supplemental information requests. The results of these analyses are presented in context of the critical questions motivating this pilot experiment.

Does graphic generalization lead to increased requests for spatial, but not verbal, detail? To test whether graphic generalization selectively increased requests for spatial details, we conducted an ANOVA of the building perimeter requests category, which revealed a main effect of graphic, $F(1, 28) = 22.892$, $p < .01$, MSE = .0000002, but not labeling, $F(2, 56) = .094$, $p > .05$, MSE = .0000009, detail. As seen in Figure 5, there are higher overall requests in the graphically-generalized relative to the graphically-detailed condition. No other categories produced significant effects of graphic detail (all *p's* > .05), demonstrating the specificity of our spatial manipulation.

Does reduced labeling detail lead to increased requests for verbal, but not spatial, detail? We first assessed whether decreases in labeling (3 levels: all, important, none) would lead to corresponding increases in requests for the eliminated verbal information; the primary categories of interest were therefore “building names” and “street names.” An ANOVA of the building names requests revealed an effect of labeling, $F(2, 56) = 39.793$, $p < .01$, MSE = .000001, but not graphic, $F(1, 28) = .001$, $p > .05$, MSE = .0000006, detail. As seen in Figure 5, there are more requests for building names when only important details are included relative to full labeling, $t(29) = 5.461$, *p*

$< .01$, and with no labeling relative to important labeling, $t(29) = 2.759$, $p < .01$. An ANOVA of the street names requests also revealed an effect of labeling, $F(2, 56) = 17.055$, $p < .01$, MSE = .000001, but not graphic, $F(1, 28) = .318$, $p > .05$, detail. As seen in Figure 5, there are more requests for street names with no labels relative to both important labels, $t(29) = 3.612$, $p < .01$, and full labels, $t(29) = 5.757$, $p < .01$. There was no difference between full label and important label conditions as would be expected since in our manipulation street names were only eliminated in no label conditions.

Other effects of graphic generalization and reduced labeling detail. No other category showed effects of either graphic generalization or labeling detail, (all *p's* > .05), demonstrating the specificity of our spatial and verbal detail manipulations, respectively.

Discussion

This pilot experiment examined the efficacy of our graphic and labeling generalization procedures. We demonstrated systematic increases in requests for verbal details as a function of successive label elimination, and a discrete increase in requests for spatial detail as a function of graphic generalization. These results were also specific to the manipulation type; that is, the labeling manipulation did not lead to increased request for spatial information and graphic generalization did not lead to increased requests for verbal information. Further, general request frequencies did not differ as a function of either spatial or verbal detail. These results speak to the robustness and specificity of our manipulation, the utility of extant generalization procedures, and the preferred nature of multi-format interfaces (supporting earlier work by Cohen et al., 1998 and Wauchope, 1996).

Experiment 1

Our first main experiment was designed to test the effects of labeling and graphic generalization on memory for map-based information. The experiment had three primary goals; first, to assess the effects of graphic and labeling generalization on the recall of map details; second, to determine the effects of graphic and labeling detail on participants' abilities to reproduce maps versus produce descriptions after learning from maps; and third, to determine the appropriate balance of graphic and labeling details for increasing memory and reducing cognitive load. With these goals in mind, the present experiment involved learning either graphically generalized or detailed maps, at three levels of labeling detail, and the subsequent recall of this information in the form of map drawing or description writing.

We hypothesized that reductions in graphic and labeling details would lead to increased memory for spatial and verbal details, respectively. That is, reductions in labeling details (label *minimizing*) will free up cognitive resources for processing spatial information, and conversely reductions in graphic details (graphic *minimizing*) will free up cognitive resources for processing verbal information. This hypothesis is based on work demonstrating the limited processing capacity of working memory (e.g., Baddeley, 1992; Sweller, 1988), reductions in memory performance as a result of cognitive overload (e.g., Bannert, 2002; Sweller, 1988), and the role of the central executive in the dynamic allocation of attentional resources between working memory subsystems in response to task demands (e.g., Baddeley, 1992, 1996; Logan, 1985; Smith & Jonides, 1999). Further, we hypothesized overall memory advantages on map drawing relative to description writing. This hypothesis is based on the notion that producing spatial descriptions following map study will increase cognitive load. Producing a description requires conceptualizing the map information into language, organizing the spatial information into the required linearity of language, and tracking the overall description for completeness (Levelt, 1993). The additional cognitive steps needed to write a description often introduce memory errors and distortions; this is supported by earlier work with maps and spatial descriptions (Taylor & Tversky, 1992b, Schneider & Taylor, 1999). Note that this study differs from the pilot experiment in that it examines memory.

We also hypothesized that decreasing labeling, particularly in the no label condition, would increase use of building category information. This hypothesis is based on the notion that detail unavailability may lead to active search, as a memory strategy, for information that would help parse and group landmarks, as suggested by studies investigating categorization and partitioning of map information in memory (McNamara, Hardy, & Hirtle, 1989; Rossano & Hodgson, 1994; Shimron, 1978). Similarly, we predicted that reduced detail would translate to more use of a survey perspective in written descriptions. While taking a tour through an environment has been suggested as a good organization strategy (Linde & Labov, 1975), increased ambiguity resulting from decreased detail would lead to active organization strategies, perhaps through use of configural information (McNamara et al., 1989; Schneider & Taylor, 1999).

Method

Participants and Design. Forty Tufts University undergraduates participated for partial course credit. The sample was randomly divided into two groups, one (n = 20) drew maps at test, and the other (n = 20) wrote descriptions. Within each group, half of the participants studied graphically generalized maps, while the other half studied graphically detailed maps. Each participant studied three maps in counterbalanced succession, with full, important, and no labeling detail. Thus the experiment had a mixed design, with dependent task (2 levels: map drawing, description writing) and graphic detail (2 levels: detailed, generalized) as between-participants factors, and labeling detail as a within-participants factor (3 levels: full detail, important detail, no detail).

Materials and Apparatus. The materials and apparatus were identical to those used in the pilot experiment, with the exception of the dependent measures. Specifically, participants completed one of two memory tasks – one involved drawing a map from memory, and one involved writing a description from memory.

Procedure. As in the pilot experiment, participants studied a map for 5 minutes with the instructions to gather all information they would use to guide a hypothetical campus tour. Following each map study session, participants completed either the map drawing or description writing task for 10 minutes. This procedure was repeated for each of the three maps. Labeling detail order was counterbalanced across participants.

Results

Map and Description Scoring. Each map was scored for the following: category usage, number of buildings drawn (spatial), number of buildings labeled (verbal; for all but no label maps), number of roads drawn (spatial), and number of roads labeled (verbal; for all but no label maps). Category usage was scored by totaling how many of the five categories (Academic, Administrative, Athletic, Residence, Theater/Arts) were included in the drawing; number of buildings drawn was scored by totaling how many buildings were drawn (labeled or unlabeled) relative to the number originally depicted; number of buildings labeled was scored by totaling how many buildings were labeled (drawn or non-drawn, such as listing building names at the bottom of the recall page) relative to the number originally labeled; number of roads drawn was scored by totaling how many roads were drawn (labeled or non-labeled) relative to the number originally depicted; and finally, number of roads labeled was scored by totaling how many roads were labeled (drawn or non-drawn) relative to the number originally labeled.

Each written description was scored for all of the above in addition to the perspective adopted in the description (i.e., survey, route, mixed survey and route). Perspective was determined by scoring for instances of egocentric terminology (e.g., turn right, go forward, on the left) indicative of adopting a route perspective, and allocentric terminology (e.g., north of the library, campus is arranged in a circular formation) indicative of a survey perspective; in the cases where participants used both types of terminology, their description was considered mixed. All scoring was collapsed across campuses, and totaled for each of the 6 map types (graphically detailed, generalized; labeling detailed, important, none).

Analysis. Five ANOVAs were conducted from the map drawing data (category use, buildings drawn, buildings labeled, roads drawn, and roads labeled), and six on the description writing data (perspective type(s) used, category use, buildings mentioned, buildings labeled, roads mentioned, and roads labeled). All planned comparisons were done using t-tests with the Bonferroni correction to account for multiple comparisons. Frequency data regarding category and perspective use were converted to proportions by dividing by the total number of requests across all categories (i.e., relative frequency), then submitting these data to arcsine transformation (i.e., Feller, 1957; Kirk, 1968); one ANOVA was conducted on category use data, and three ANOVAs were conducted on each perspective (route, survey, mixed) data. See Table 2 for a summary of map drawing and description writing data. See Figure 6 for a sample of map drawing. Note that all tabulated and graphed data use proportion values prior to arcsine transformation for interpretability. As with the pilot experiment, the results are presented around the critical questions motivating this experiment.

How does labeling and graphic generalization affect map-based memory?

Map Drawing. An example map is depicted in Figure 6, demonstrating the general overall accuracy, in this case following study of the Beloit College based map with detailed graphic and full labeling detail. An ANOVA of category use revealed an effect of labeling detail, $F(2, 36) = 21.445$, $p < .01$, MSE = .072, with increased category use in the important label condition relative to the full label condition, $t(19) = 3.308$, $p < .01$, and in the no label condition relative to the important label condition, $t(19) = 3.518$, $p < .01$; there was no effect of graphic detail on category use ($p > .05$). An ANOVA of buildings drawn revealed an effect of graphic detail, $F(1, 18) = 24.336$, $p < .01$, with more buildings included in the graphically generalized relative to graphically detailed group; there was no effect of labeling detail ($p > .05$).

An ANOVA of buildings labeled revealed an effect of graphic detail, $F(1, 18) = 10.965$, $p < .01$, with more buildings labeled in the graphically generalized relative to graphically detailed group, and an effect of labeling detail, $F(1, 18) = 63.703$, $p < .01$, with more buildings labeled in the important label relative to the full label condition. Recall that this is proportion of labels included. Further, an interaction between graphic and labeling detail, $F(1, 18) = 5.844$, $p < .05$, revealed that the effect of graphic detail was primarily driven by differences within the important label condition; that is, the number of building labeled following graphically generalized, relative to detailed, was only higher, $t(18) = 3.484$, $p < .01$, when labeling detail was limited.

An ANOVA of roads included revealed an effect of graphic detail, $F(1, 18) = 8.039$, $p < .01$, with more roads included in the graphically generalized relative to the graphically detailed group, but no effect of labeling detail ($p > .05$). An ANOVA of roads labeled revealed an effect of graphic detail, $F(1, 18) = 4.937$, $p < .05$, with more road labeled in the graphically generalized relative to graphically detailed group, but no effect of verbal detail ($p > .05$), which would be expected.

Description Writing. An ANOVA of category use revealed an effect of labeling detail, $F(2, 36) = 58.110$, $p < .01$, MSE = .025, with greater category use in the important label condition relative to the full label condition, $t(19) = 3.867$, $p < .01$, and in the no label condition relative to the important label condition, $t(19) = 6.241$, $p < .01$; there was no effect of graphic detail on category use ($p > .05$). An ANOVA of buildings included did not reveal effects of either graphic or labeling detail (p's $> .05$).

An ANOVA of buildings labeled revealed an effect of graphic detail, $F(1, 18) = 5.412$, $p < .05$, with more buildings labeled in the graphically generalized relative to graphically detailed group, and an effect of labeling detail, $F(1, 18) = 48.301$, $p < .01$, with more buildings labeled in the important label relative to the full label condition. Further, an interaction between graphic and labeling detail, $F(1, 18) = 6.792$, $p < .05$, revealed that the effect of graphic detail was primarily driven by differences within the important label condition; that is, participants only provided more building labels for graphically generalized maps, relative to detailed ones, when labeling was limited, $t(18) = 2.514$, $p < .05$.

An ANOVA of roads included did not reveal effects of graphic or labeling detail (p's > .05). An ANOVA of roads labeled revealed a main effect of graphic detail, $F(1, 18) = 6.000$, $p < .05$, with more roads labeled in the graphically generalized relative to graphically detailed group, but no effect of labeling detail ($p > .05$), as would be expected.

Separate ANOVAs examined spatial perspective use as a function of the information provided. An ANOVA examining use of route perspective language did not reveal effects of labeling or graphic detail (all p's > .05). Use of survey perspective language revealed an effect of labeling detail, $F(2, 36) = 9.222$, $p < .01$, MSE = .00004, with more survey terminology used in the no label condition relative to both the full, $t(19) = 3.559$, $p < .01$, and important, $t(19) = 4.359$, $p < .01$, label conditions, but no effect of graphic detail. An ANOVA of mixed (survey and route) perspective language did not reveal effects of labeling or graphic detail (all p's > .05).

Are there memory advantages for map drawing, relative to description writing, following map study? ANOVAs of information included as a function of task showed greater information inclusion in map drawing relative to description writing. This was true for buildings included ($F(1, 36) = 43.095$, $p < .01$), buildings labeled ($F(1, 36) = 20.415$, $p < .01$), roads included ($F(1, 36) = 605.588$, $p < .01$), and roads labeled, ($F(1, 36) = 131.275$, $p < .01$). The results also showed an interaction between graphic detail and dependent measure, $F(1, 36) = 18.079$, $p < .01$, for buildings included. This interaction showed that the dependent measure main effect was constrained to the graphically generalized maps, $t(18) = 10.723$, $p < .01$. In other words, participants only included more buildings during map drawing, compared to description writing, if they had studied a graphically generalized map.

Discussion

Varying levels of graphic and labeling details on maps affects memory in robust and interesting ways. Our discussion of these findings is structured around the primary motivations behind Experiment 1; first, we consider the memory effects of varying graphic and labeling details on recalling map details through map drawing and writing descriptions. Second, we consider the application of these data to geographical interface design by discussing the interaction between graphic and labeling information, and suggestions for the effective and appropriate balancing of these two information types.

What are the effects of graphic and labeling generalization on memory for map-based information? The present set of dependent measures and scoring procedures allowed us to examine a variety of information types that individuals might recall after learning from a campus map, and the impact of graphic and labeling generalization on these measures. In the map drawing task we found a consistent effect of graphic generalization whereby studying maps with generalized graphics led participants to recall more, including more buildings, more roads, and more road labels, relative to studying maps with detailed graphics. Labeling detail, however, affected recall of these information types to a lesser extent. Specifically, only when labeling buildings did labeling detail affect performance, in the form of increased labeling following study of important, relative to full, labeling details. Note that labeling recall was coded as a proportion of the labels included on the studied map, rather than as an absolute number. Interestingly, this effect interacted with the graphic information such that only following study of maps with important labels were effects of graphic generalization seen. In other words, when full labeling was provided, graphic generalization did not improve building labeling; however, when only important labels were provided, graphic generalization improved building labeling. Overall, these results demonstrate that graphic generalization can lead to improved memory for both landmark existence (buildings, roads) and landmark identity (labels) information.

This effect is likely due to at least two processes; first, graphic generalization substantially reduces the number of buildings to learn, likely reducing the cognitive load associated with memorizing and recalling an otherwise large number of map details. As a result of reduced cognitive load (i.e., Paas, Renkl, & Sweller, 2003; Sweller, 1988), participants appear to be able to process, store, and subsequently recall a higher proportion of map details while re-drawing the map. Second, and from a process-based perspective (i.e., Baddeley, 1992), graphic generalization may reduce visuospatial load, allowing the central executive to allocate more resources to articulatory working memory, which may be particularly important for processing map labels.

In description writing, we found a relatively inconsistent effect of graphic generalization whereby only two measures (building labels, road labels) revealed effects of graphic generalization. Labeling density again produced two effects, in the form of a main effect and an interaction with graphic detail when measuring building labels, complementing the map drawing data. Overall, these results demonstrate that graphic generalization only imparts memory benefits during description writing in terms of labels included, building or road. Also, they point at a critical difference between the dependent measures of map drawing and description writing. Map drawing may lead to a focus on visual details during recall (e.g., building outlines, road structure), while the description writing may induce a focus on verbal information, such as labels. In addition, across tasks, graphic generalization only increased use of building labels when labeling information was limited during study, suggesting inherent limitations to information processing capacities. Thus, while memory for labels can be improved via graphic generalization, this only happens when there are a limited number of, in the present case, building labels.

In contrast to our results with graphic generalization, we found little evidence for labeling density affecting memory. In two cases, building label use in both map drawing and description writing, increased for important labels relative to all labels. This effect is likely due to working memory constraints; given the short amount of time participants had to study, it was unlikely they could encode and subsequently recall all details. It is also important to note that both main effects of labeling were complemented by interactions between graphic and labeling detail, suggesting that memory benefits of label density only existed when complemented by graphic generalization. Overall, these results support the notion that working memory systems draw from a common resource pool that allocates support of spatial and verbal systems as a function of attentional demands.

Are there memory benefits for map drawing, relative to description writing, following map study? We hypothesized that, following map study, memory advantages would be partially a function of recall task type; specifically, map drawing was expected to produce memory advantages relative to description writing since description writing requires additional cognitive processing. Overall, our hypothesis was supported, with all of our scoring measures demonstrating greater overall recall of buildings, building labels, roads, and road labels when participants drew maps from memory, relative to when they wrote descriptions. This result is likely due to two processes. First, transfer appropriate processing theory posits increases in memory performance with increases in overlap between the processing characteristics of acquisition and retrieval (e.g., Blaxton, 1989; Morris, Bransford & Franks, 1977), such as might be seen when studying, and then drawing, maps. Related, if propositional mental representations (i.e., Kintsch & Van Dijk, 1978) derived from maps are closely tied to the surface features of the learning format (as suggested, for example, by Taylor & Tversky, 1992b), one might expect a high degree of cognitive load associated with recalling details across, relative to within, formats. This notion will be further examined in Experiment 2, when we compare these dependent measures following description study.

Implications for Handheld Device Design. The present experiment demonstrated the importance of carefully-designed spatial information interfaces for facilitating memory. While we cannot speak to potential navigation performance based on studying graphically- and labeling-generalized maps, the immediate cognitive effects of these manipulations are quite clear. First, graphic generalization procedures can reduce the cognitive load associated with processing highly detailed space, freeing up cognitive resources for deeper processing of information that may be deemed important for the task at hand (e.g., wayfinding or touring). For example, when trying to find your way from Ballou Hall to the Psychology Department at Tufts, one can expect memory advantages for important details (buildings, roads, and labels) contained in Figure 1b, without introducing details largely irrelevant to this task, as done in Figure 1a. However, in the case of a person wanting to find East Hall (see Figure 1), the amount of detail provided by a graphically generalized map may not provide sufficient building perimeter information to expedite such a task. That is, finding the precise location of East Hall may be quite difficult if it is generalized within a large Residential category containing several small buildings. Thus, Experiment 1 has presented a case for graphic *minimizing*, but with the caveat that generalization procedures should be used only within the context of task goals.

Second, labeling detail only imparts memory benefits when complemented by graphic generalization, again emphasizing the importance of graphic detail level in displaying geographic information. Thus, Experiment 1 provides an important design principle for geographic information displays: memory advantages can be imparted through the reduction of graphic detail through established cartographic generalization procedures, but the use of such procedures should carefully consider user goals, operationalized in this study through different dependent measures.

Pilot Experiment 2

Experiment 1 demonstrated that graphic generalization on maps imparted memory benefits, particularly during map drawing, and to some extent during description writing. Experiment 2 was designed to test a similar set of hypotheses as Experiment 1, but in the context of studying spatial descriptions. Thus, Pilot Experiment 2 examines whether our graphic and labeling detail manipulations, as applied to spatial descriptions, were substantial enough to lead participants to increase rates of requested information as provided information decreased through level of detail manipulations. That is, as in Pilot Experiment 1, will decreases in spatial and labeling detail in descriptions lead to corresponding increases in requests for information?

Participants studied three spatial descriptions and then wrote a list of any supplemental information they would like to have. We predicted that reductions in spatial detail would lead to increases in requests for spatial (but not verbal) information, while reductions in labeling detail would lead to increases in requests for verbal (but not spatial) information. Other requests should remain consistent across levels of spatial and labeling detail. If these hypotheses are supported, it would demonstrate that our manipulation is phenomenologically noticeable and shows specificity; that is, our manipulations are powerful enough to produce substantial differences in the way participants view (and potentially use) our descriptions, and detail manipulations will induce specific requests. If supported, these hypotheses will potentially complement the findings with maps in Pilot Experiment 1.

Method

Participants and Design. Thirty Tufts University undergraduates participated for partial course credit. Fifteen participants studied spatially generalized and fifteen studied spatially detailed descriptions. As in Pilot Experiment 1, each group studied three (labeling: full, important, none) descriptions in counterbalanced succession.

Materials and Apparatus. To serve as stimuli, we needed to create a set of descriptions that would represent the same environments used in Pilot Experiment 1 and Experiment 1, yet also reflect the descriptions participants wrote during testing in Experiment 1. Six descriptions were created for each campus map, two levels of spatial detail (detailed, generalized), and three levels of verbal detail (all, important, none), for a total of 18 descriptions (see Table 3 for sample descriptions). Spatial generalization was done using a verbal adaptation of established cartographic generalization procedures

(McMaster & Shea, 1992); two detail levels were produced, spatially detailed and spatially generalized. The spatially detailed descriptions noted precise building and category perimeters, and walking paths (e.g., Table 3a), while spatially generalized descriptions grouped buildings by space (outer perimeter boundaries) and category (high frequency membership) (e.g., Table 3b). Labeling was done as with maps resulting in three detail levels: full labeling detail (e.g., Table 3a), important labeling detail, and no labeling (e.g., Table 3b). Full detail included labels for every building and road, important detail included labels for all roads, and buildings determined as important to a campus tour (see Pilot Experiment 1), and no labels excluded all labels (aside from categories). All descriptions were written such that they matched the majority perspectives (route) and organization (breadth then depth) used by participants in the Experiment 1 description writing task. Specifically, all were written using a route perspective, analogous to a first-person tour through the campus; half of the descriptions also included a brief overview paragraph that described the configuration of the environment from a survey perspective, and half did not. We note that an interesting result from Experiment 1 that carries over into the present experiment is that participants tended to write descriptions in both survey and route perspective, primarily using the former to briefly structure the environment and the latter to guide the reader on a tour through the environment. The present descriptions matched this structure.

All descriptions were presented in succession, one at a time, on a sheet of 8.5” x 11” white paper. The dependent measure was administered on a blank sheet of paper with brief instructions outlining the task to write down requests for supplemental information.

Procedure. All procedures were identical to Pilot Experiment 1, with the exception that participants studied descriptions rather than maps.

Results

Scoring and Analysis. All scoring and analysis procedures were identical to Pilot Experiment 1. See Table 4 for a summary of supplemental information request data.

Does spatial generalization lead to increased requests for spatial, but not verbal, detail? To test whether spatial generalization selectively produces increased requests for spatial details, we conducted an ANOVA of the building perimeter requests, which revealed a main effect of spatial, $F(1, 28) = 19.641$, $p < .01$, MSE = .0000002, but not labeling, $F(2, 56) = .104$, $p > .05$, MSE = .0000005, detail. As seen in Figure 7, there were more requests in the spatially-generalized relative to the spatially-detailed condition. No other categories showed effects of spatial detail (all *p's* > .05), demonstrating the specificity of our spatial manipulation.

Does labeling detail lead to increased requests for verbal, but not spatial, detail? We first assessed whether decreasing labeling density (3 levels: all, important, none) would lead to corresponding increases in requests for the eliminated verbal information; the primary categories of interest were therefore "building names" and "street names." An ANOVA of the building names requests revealed an effect of labeling, $F(2, 56) = 39.345$, $p < .01$, MSE = .0000006, but not spatial, $F(1, 28) = .001$, $p > .05$, MSE = .0000002, detail. As seen in Figure 7, there were more requests for building names in the important condition relative to the full condition, $t(29) = 6.381$, $p < .01$, and in the no label condition relative to the important condition, $t(29) = 2.604$, $p < .01$. An ANOVA of the street names requests revealed an effect of labeling, $F(2, 56) = 12.763$, $p < .01$, MSE

= .0000008, but not spatial, $F(1, 28) = .037$, $p > .05$, detail. As seen in Figure 7, there were more requests for street names in the no label condition relative to both the important, $t(29) = 3.340$, $p < .01$, and full, $t(29) = 5.113$, $p < .01$, conditions; there was no significant difference between the full and the important conditions, in line with the expected effect of our manipulation (i.e., street names were only eliminated in the no label condition).

Other effects of graphic generalization and reduced labeling detail. As found in Pilot Experiment 1, no other category showed effects of either graphic generalization or labeling detail, (all *p's* > .05), demonstrating the specificity of our spatial and verbal detail manipulations, respectively.

Discussion

Our second pilot experiment examined the efficacy of our generalization procedures as adapted to spatial descriptions. As with our maps, our descriptions produced systematic increases in requests for verbal details as a function of decreases in labeling density, and increases in requests for spatial details as a function of spatial generalization. Again, the results were specific to the manipulation type. These results speak to the robustness and specificity of our manipulation as it applies to spatial descriptions, complementing the results of Pilot Experiment 1 with maps.

Experiment 2

Experiment 2 was designed to test the effects of generalizing spatial and verbal information presented within descriptions, in an analogous manner to that done in Experiment 1 with maps. There are two overall goals of this experiment; first, we are interested in the potential effects of spatial generalization and labeling density on memory for spatial descriptions, providing unique insight into the effects of these manipulations on presenting spatial information through language, rather than maps. Motivation comes from research with spatial descriptions demonstrating the effectiveness of this format (equivalent to that of maps) when participants form spatial mental models, but not necessarily when they form propositional representations (Taylor & Tversky, 1992b). Second, while most geographic information systems display spatial images complemented by labels, we examine the possibility that there may be utility (e.g., mnemonic, explanatory, maximizing screen space) for certain types of descriptive information to be displayed. This point is especially important given the current practice to produce smaller and lighter spatial interfaces, necessitating smaller screen sizes and more effective information generalization and consolidation procedures.

In consideration of Experiment 1 results, a series of hypotheses motivate the present experiment. First, we expect that spatial generalization will have a small effect on memory for information as applied to map drawing, relative to its robust effects in Experiment 1; this hypothesis is driven by the fundamental differences between maps (symbolic) and description (abstracted) representational forms (Mani & Maybury, 1999; Perrig & Kintsch, 1985; Sparck-Jones, 1997, 1999; Taylor & Tversky, 1992a, 1992b). Specifically, symbolic representations such as maps (relative to descriptions) may facilitate a focus on spatial information, such as the configural details, as they comprise the majority of displayed content. In contrast, abstracted representations such as descriptions (relative to maps) may facilitate a focus on propositional information, such as building and road labels, as they may be quite easy to derive (especially compared to configural information) from the route-perspective descriptions (especially without a survey goal; i.e., Taylor, Naylor, & Chechile, 1996). These ideas also fall in line with ideas of transfer appropriate processing (e.g., Blaxton, 1989; Morris, Bransford & Franks, 1977). Second, we expect that in contrast to Experiment 1, labeling density will increase recall of building and road information; this hypothesis is based on the notion that decreases in verbal working memory demands will increase the cognitive resources devoted to the theoretically difficult process of gathering spatial information from descriptions (especially when reading a description only once; i.e., Bosco, Filomena, Sardone, Scalisi, & Longoni, 1996). Finally, relative to Experiment 1, spatial descriptions may not impart memory benefits due to their single-format nature; that is, any multimedia benefits accrued as a function of multi-format information contained in maps (i.e., images and icons with text labels) should not be apparent with spatial descriptions.

Method

Participants and Design. Twenty Tufts University undergraduates participated for partial course credit. The sample was randomly divided into two groups, one (n = 10) which studied spatially generalized descriptions, and one (n = 10) that studied spatially-detailed descriptions. Each participant studied three descriptions in counterbalanced succession, one with full, one with important, and one with no labels. Note that in contrast to Experiment 1, we did not vary test type (effectively halving our sample size). We therefore incorporated a mixed design, with spatial detail (2 levels: detailed, generalized) as a between-participants factor, and labeling as a within-participants factor (3 levels: full detail, important detail, no detail).

Materials and Apparatus. The materials and apparatus were identical to those used in the second pilot experiment, with the sole exception of the dependent measures. Specifically, participants completed one dependent task involving drawing a map of the studied environment from memory on sheet of blank paper.

Procedure. As in Experiment 2, participants studied each description for a total of 5 minutes with the instructions to gather all information they would use to guide a hypothetical upcoming campus tour. Following each description, participants drew a map of the described environment for 10 minutes. The order in which each description type was studied was counterbalanced.

Results

Scoring and Analysis. All map scoring procedures and analyses were identical to those used in Experiment 1. See Table 5 for a summary of map drawing data.

What are the effects of spatial generalization and labeling density on memory for description-based information? An ANOVA of category use revealed a main effect of labeling, $F(2, 36) = 18.988$, $p < .01$, MSE = .070, with more category use in the important label condition relative to the full condition, $t(19) = 3.426$, $p < .01$, and in the no label condition relative to the important label condition, $t(19) = 3.603$, $p < .01$; there was no effect of spatial detail on category use ($p > .05$). An ANOVA of buildings drawn revealed an effect of spatial detail, $F(1, 18) = 5.539$, $p < .05$, MSE = .0386, with more buildings included in the spatially-generalized relative to spatially-detailed group; there was no effect of labeling density ($p > .05$). An ANOVA of buildings labeled revealed an effect of spatial detail, $F(1, 18) = 4.668$, $p < .01$, MSE = .0288, with more buildings labeled in the spatially-generalized relative to spatially-detailed group, and an effect of labeling, *F*(1,

18) = 50.018, $p < .01$, MSE= .0415, with more buildings labeled in the important label relative to the full label condition. ANOVAs of roads recalled and roads labeled did not reveal effects of spatial or label information (all *p's* > .05).

Discussion

Experiment 2 adapted our spatial generalization and labeling density procedures to spatial descriptions. The results were strikingly similar to those of Experiment 1 using maps, particularly for inclusion and labeling of buildings within the environment. The effects on the inclusion of roads and road labels was not seen, even though the descriptions took a route perspective, taking participants on an imaginary tour upon the roads. Overall, we were able to uniquely demonstrate the memory effects of varying levels of spatial and labeling detail within spatial descriptions; accordingly, the results are discussed within the framework of the two primary motivations for this experiment. First, we consider memory effects of varying levels of spatial and labeling detail in descriptions; second, we consider the application of these findings to geographical interface design, and the balancing of spatial and verbal information.

What are the effects of spatial generalization and labeling density on memory for description-based information? The effects of generalizing information within spatial descriptions are remarkably similar to doing so within maps. We found increased use of categorical information with reductions in labeling detail, emphasizing the importance of information that aids in parsing and grouping information, and extending previous work with maps to spatial descriptions (McNamara et al., 1989; Rossano & Hodgson, 1994; Shimron, 1978). These results also support earlier work demonstrating the hierarchical structure of memory, further suggesting the importance of schema availability for facilitating memory for spatial descriptions (Taylor & Tversky, 1992a).

The present results also speak to the value of spatial generalization for increasing memory for both spatial (buildings) and verbal (labels) information within descriptions, but not for all information within the description. Specifically, while buildings and building labels demonstrated this advantage, roads and road labels did not. Both building and road use were affected by similar manipulations with maps. These results may reflect differences in the final memory representations resulting from descriptions compared to maps. Roads may provide a perceptually-salient organizational scheme when studying maps (McNamara, Ratcliff, & McKoon, 1984) and may facilitate hierarchical grouping; however, when reading spatial descriptions, particularly those from a route perspective, the roads serve more as a means of traveling between described buildings on the campus. In light of recent work with route descriptions (Daniel & Denis, 2004), this finding can be attributed to the importance of landmarks and the actions between them; in the present case the roads may only be pertinent to the actions that can take place between buildings.

Implications for Handheld Device Design. The present experiment again demonstrated the importance of carefully-designed spatial information interfaces for facilitating memory. Interestingly, absolute memory was quite similar whether studying maps or descriptions. This point suggests the efficacy of descriptions in conveying spatial information, in line with Taylor and Tversky's (1992b) findings when comparing memory effects of maps and spatial descriptions. Cognitively, this result suggests similar final memory representations across acquisition formats. In a practical sense, this result informs design guidelines for geographical interfaces; specifically, spatial information need not be constrained to depictions, but rather designers might consider the utility of presenting particular types of information in descriptions or appropriately combining descriptions and depictions. Similar to what we found in Experiment 1, the present study suggests the power of spatial *minimizing* and extends this to spatial descriptions, especially in cases where buildings (and their labels) are critical to the spatial information one is trying to gather or the task they are trying to complete. These results complement work (Allen, 2000) with route descriptions that has demonstrated clear advantages of: maintaining temporal-spatial order, concentrating choice-point information, and using common spatial designations (e.g., ‘north’ versus ‘up the road’).

General Discussion

Devices presenting geographic information increasingly have interfaces that use both spatial and verbal representations to convey information about environments. However, surprisingly little empirical research has been devoted to determining the potential memory effects of these combinations and how such information can be combined to best maximize cognitive success. The present experiments represent a step towards understanding level of detail interactions between descriptions and depictions within the contexts of geographical and cognitive science. We hope to motivate future work examining additional influences on map comprehension and memory, such as the visual features of text labels (e.g., font size and style), the structure of landmarks (e.g., 2D versus 3D), and multiple modality presentations (e.g., auditory labels).

The present adaptation of graphic generalization and labeling density to college campus maps and descriptions was surprisingly effective at selectively influencing requests for supplemental information. They also showed interesting memory effects associated with maximizing and minimizing informational content that have implications for design principles in hand-held in in-vehicle navigation systems. The design principles are based on the goal of improving memory for the information provided. The present findings regarding the utility of varying multiple information formats complement recent work examining their usability towards navigation (Agrawala & Stolte, 2001; Frank, 2003; Tomko & Winter, 2006). The obvious next step would be determining how variations in *both* spatial and verbal generalization principles would affect wayfinding and navigation.

Our first suggested principle is that maximizing information is not always better. We were also able to present a strong case for the memory advantages that can occur as a function of both spatial and (perhaps to a lesser extent) verbal generalization. Technological advances in small screen resolution should not be accompanied by increases in graphic density of displayed geographic information, either through maps or descriptions. Graphic generalization in maps and spatial generalization in descriptions leads to concomitant reductions in cognitive load, freeing up mental resources to process, store, and recall more information overall. More is also not better in terms of labeling. Increased memory after studying graphically generalized information showed particularly strong effects when labeling detail was also limited, but not eliminated.

Our second suggested design principle is to take advantage of cognitive benefits of the multimedia advantage. Much of the extant literature examining multi-format presentation has focused on declarative, and to a lesser extent, procedural information. The interactions between graphic and labeling detail in the current studies suggest similar benefits of multi-format displays to presentations of geographic information.

Our third suggested design principle is to know the user's goal or task. Evidence of transfer appropriate processing (Blaxton, 1989; Morris, Bransford & Franks, 1977) appeared in many facets of the current studies, from a match of information requested to information manipulated and reflections of study format in recall format (map drawing or description writing). The relative levels of graphic and labeling detail should align with how information is being used, and interfaces should show flexibility based on user input.

Technological advances in relating spatial information have proceeded at a faster pace than cognitive scientists' understanding of how these technological changes impact learning, memory, and use of navigational systems. Critically, while spatial technologies are getting lighter and more compact, accessibility to increasingly detailed global geographical information is growing at an rapid rate. This presents a clear challenge for interface designers to identify, capture, and display relevant pieces of information on increasingly small displays; the question therefore becomes: which information should be displayed at what level of detail, for any given task? The present studies suggest that subtle manipulations in verbal and spatial details can have large influences on people's ability to gather, memorize, and retrieve geographical information. They also present a case for the importance of identifying and leveraging the interactive balance between verbal and spatial details, and doing so within the context of task demands. Technological complexity and power will continue to advance, the present studies provide suggestions on how to best use these advances in matching human information processing capabilities.

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Table 1. Pilot Experiment 1 information request proportion means and standard deviations as a function of verbal and spatial detail, for all scoring procedures. Data are presented as the request frequencies converted to a proportion by dividing them by the total number of requests across all categories (i.e., relative frequency).

	Verbal Detail Condition					
	Full Text		Important Text		No Text	
Scoring Procedure	*M*	*SD*	*M*	*SD*	*M*	*SD*
Building Names						
Spatially Detailed	.000	.000	.001	.001	.002	.001
Spatially Gen.	.000	.000	.001	.001	.003	.001
Street Names						
Spatially Detailed	.0004	.001	.001	.001	.002	.001
Spatially Gen.	.0004	.001	.001	.001	.002	.001
Building Perimeters						
Spatially Detailed	.000	.000	.000	.000	.000	.000
Spatially Gen.	.001	.001	.001	.001	.001	.001
Dining						
Spatially Detailed	.001	.001	.001	.001	.001	.001
Spatially Gen.	.001	.001	.001	.001	.001	.001
Entertainment						
Spatially Detailed	.0004	.0001	.0005	.0001	.0004	.0001
Spatially Gen.	.0004	.0001	.0004	.0001	.0004	.0001
Housing						
Spatially Detailed	.0004	.001	.0005	.001	.0006	.001
Spatially Gen.	.0006	.001	.0005	.001	.0005	.001
Key Locales						
Spatially Detailed	.002	.005	.002	.003	.002	.004
Spatially Gen.	.002	.005	.002	.004	.001	.002
Landscape						
Spatially Detailed	.0002	.001	.0002	.001	.0002	.003
Spatially Gen.	.0002	.001	.0003	.002	.0001	.001
Map Features						
Spatially Detailed	.001	.002	.001	.001	.001	.001
Spatially Gen.	.001	.002	.002	.002	.002	.002
Parking						
Spatially Detailed	.0007	.001	.0004	.001	.0007	.001
Spatially Gen.	.0006	.001	.0007	.001	.0007	.001
Scale						
Spatially Detailed	.0008	.001	.0008	.001	.0009	.001
Spatially Gen.	.0008	.001	.0009	.001	.0008	.002
Services						
Spatially Detailed	.0004	.002	.0001	.001	.0002	.001
Spatially Gen.	.0002	.001	.0002	.001	.0003	.002
Transportation						
Spatially Detailed	.001	.002	.002	.002	.001	.002
Spatially Gen.	.001	.002	.001	.002	.001	.002

Table 2. Experiment 1 means and standard deviations as a function of verbal and spatial detail, for all dependent measures and scoring procedures.

	Verbal Detail Condition					
	Full Text		Important Text		No Text	
Measure and Scoring Procedure	*M*	*SD*	*M*	*SD*	*M*	*SD*
Map Drawing						
Category Use						
Spatially Detailed	.20	.13	.48	.23	.82	.32
Spatially Gen.	.28	.25	.43	.31	.76	.32
Buildings Drawn						
Spatially Detailed	.56	.23	.47	.25	.66	.20
Spatially Gen.	.86	.11	.91	.07	.89	.07
Buildings Labeled						
Spatially Detailed	.19	.06	.46	.35	--	--
Spatially Gen.	.22	.10	.88	.15	--	--
Roads Drawn						
Spatially Detailed	.81	.13	.88	.10	.87	.18
Spatially Gen.	.93	.07	.94	.12	.94	.09
Roads Labeled						
Spatially Detailed	.62	.26	.61	.32	--	--
Spatially Gen.	.80	.21	.82	.27	--	--
Description Writing						
Perspective Use						
Route						
Spatially Detailed	.005	.008	.003	.007	.001	.001
Spatially Gen.	.006	.008	.005	.008	.003	.007
Survey						
Spatially Detailed	.005	.008	.005	.008	.015	.005
Spatially Gen.	.007	.009	.003	.007	.010	.009
Mixed						
Spatially Detailed	.006	.009	.008	.009	.002	.005
Spatially Gen.	.003	.007	.008	.009	.003	.007
Category Use						
Spatially Detailed	.32	.14	.46	.16	.82	.20
Spatially Gen.	.40	.08	.46	.23	.78	.15
Buildings Drawn						
Spatially Detailed	.47	.09	.45	.12	.50	.10
Spatially Gen.	.45	.19	.53	.14	.44	.18
Buildings Labeled						
Spatially Detailed	.07	.04	.27	.14	--	--
Spatially Gen.	.08	.06	.52	.28	--	--
Roads Drawn						
Spatially Detailed	.20	.13	.48	.23	.82	.32
Spatially Gen.	.28	.25	.43	.31	.76	.32
Roads Labeled						
Spatially Detailed	.29	.12	.25	.15	--	--
Spatially Gen.	.24	.19	.29	.23	--	--

Table 3a. *Spatial description with full spatial and labeling detail.*

The overall shape of this campus is a vertically elongated rectangle. There are three major east-west running roads. Bushnell St. forms the southern border. Emerson St. divides the campus in half. District St. forms the northern border. There are two major north-south running roads. Pleasant St. forms the western border and Church St. forms the eastern border.

The campus buildings can be grouped into five categories: administration buildings, academic buildings, theater/arts buildings, residence buildings, and athletic buildings. The administration buildings, academic buildings, and theater/arts buildings are primarily distributed throughout the southern half of campus. The residence buildings and athletic facilities can be primarily found in the north half of the campus with the residence buildings on the eastern side and the athletics facilities on the western side.

This tour will give detailed information about campus locations. Begin your campus tour at the intersection of District St. and Church St., heading south on Church St. You will see a number of residence buildings on your right. First is Emerson Apartments and behind this Chapin Hall. Next you will find Peet Hall. Turn right onto Clary St. where you will see, on your left, the Outdoor Club, an athletic building, followed by Coughly House, another residence. On your right, along Clary St. you will find more residence halls: Bushnell Hall, Blaisdell Hall, and Aldridge Hall. Behind Aldridge Hall and to the right is Whitney Hall. Clary St. then dead-ends into College St. Turn left. As you go along you will pass, on your left, Alpha Sigma, French House, Theta Pi, College House, all residences, and finally Career Services, an administration building. On your right, along this stretch of road, you will see Porter Hall, Tau Kappa, Phi Kappa, Sigma Chi, College Hall, and Emerson Hall, all residences. Behind Sigma Chi is Wood Hall and behind College Hall is Haven Hall. Turn left onto Emerson St. where you will see, on your right, the Hull Center, an academic building, followed by the Music House, a residence hall. On your left you will see three more residences, the Russian House and then Voces Latinas. Behind Voces Latinas is Alliance House. You are now back at Church St.

Turn right onto Church St. You will pass, in order on your right, the Residence Hall, Womyn’s Center and Human Resources (both administrative), Spanish House (residential), and the Emeritus Offices (administrative). Turn right onto Chapin St. where you will see the Admissions Office (administrative) and Blaisdell House (residence), on your left, and the International House (administrative) and the President’s House (residential), on your right. Here Chapin St. dead-ends into College St. Turn right onto College St. The President’s house will be on your right followed by Dyson Hall, an academic building. College St. turns into a cul-de-sac. As you go around, you will see Morse Library, on your right, and when you have made it almost all the way around Eaton Chapel will be on your right. Both of these buildings are theater/arts. Head back toward Chapin St. You will see Middle College, an administration building, on your right, fairly far from the road. After you pass Chapin St. on your left, you will again see Blaisdell House, also on your left, followed by Public Affairs, an administration building. On your right you will pass the World Affairs Center then the Godfrey Building, both academic buildings, and finally Logan Museum, a theater/arts building.

Turn right onto Bushnell St. As you continue, you will again see the Logan Museum, after which is a cul-de-sac. After the cul-de-sac is the Neese Theater. Behind the Neese Theater you can see the Wright Museum and the Wright Art Hall (both theater/arts buildings), two parts of one large building. Shortly after this you will come to Pleasant St.

Turn right onto Pleasant St. Campus buildings along Pleasant St. will all be to your right. After again passing Neese Theater and Wright Art Hall, South College, an academic building, is the first building that you come to. It is fairly far from the road. Next you will see the Smith Building, also an academic building, followed by the Physical Plant and then Pearsons Hall, both administration buildings. Next is the Mayer Theater, behind which you can see the Wood Conservatory (both theater/arts). Last along this stretch of Pleasant St. is Chamberlain Hall, an academic building. Behind Chamberlain Hall, along Emerson St., you can see Morse-Ingersall Hall, also an academic building.

Continue on Pleasant St., passing Emerson St. on your right. As you go along you will see Marvin Field House and then Flood Arena, two parts of one large athletic building. The Tennis Courts are behind Flood Arena. Continuing, you will pass two residence halls, Whitney Hall and Maurer Hall, both fairly far from the road. Turn right onto District St. As you go along you will see Chapin Hall and the Emerson Apartments. You have now returned to where you started.

Table 3b. *Spatial description with generalized spatial and no labeling detail.*

The overall shape of this campus is a vertically elongated rectangle. There are three major east-west running roads, one dividing the campus nearly in half. There are two major north-south running roads.

The campus buildings can be grouped into five categories: residence, athletics, administration, academic, and theater/arts. The residences and athletics areas can be found primarily in the north half of the campus with the residences on the eastern side and the athletics facilities on the western side. The administration, academic, and theater/arts areas are distributed primarily throughout the southern half of campus.

This tour will provide the general layout of the campus. Begin your campus tour at the northeast corner of campus heading south. You will see a cluster of residences on your right. Turn right onto a side street where you will see the continuation of the residence area on your right and another residence area on your left. This side street dead-ends into another side-street. Turn left. The residences areas on your right and left continue. Turn left onto the central dividing road where you will see, on your left, the same residence area**.** You are now back to the road you started on.

Turn right. The first thing you will pass on your right is a small residence area. Next comes an administration area, also on your right. Turn right onto a side street where you will see where you will see another administrative area on your left. On your right you will pass another small residence area. Your current side street dead-ends into another. Turning right onto this street takes you around a cul-de-sac, passing the same residence area on your right. As you go around the cul-de-sac, you will see a theater/arts area on your right. Head back the way you came and continue past the side street. On your right, you will pass an academic cluster.

At the next major road, turn right. As you continue, you will see, on your right, a theater/arts area along this stretch of road. Shortly after this you will come to another major intersection.

Turn right. Campus buildings along this street will all be to your right. On the first section of this road, you will pass campus areas you have seen previously. First is the theater/arts area you just saw followed by the academic cluster. After these is an administration area. Next is a theater/arts area, half of which you saw from the cul-de-sac. Last along this stretch, but primarily running along the central dividing road, is an academic area

Continue on, passing the center dividing road on your right. As you go along you will see a cluster of athletic facilities. Turn right at the next intersection. As you go along you will pass part of the residence area you first saw on this tour. You have now returned to where you started.

Table 4. Pilot Experiment 2 information request proportion means and standard deviations as a function of verbal and spatial detail, for all scoring procedures. Data are presented as the request frequencies converted to a proportion by dividing them by the total number of requests across all categories (i.e., relative frequency).

	Verbal Detail Condition					
	Full Text		Important Text		No Text	
Scoring Procedure	*M*	*SD*	*M*	*SD*	*M*	*SD*
Building Names						
Spatially Detailed	.0001	.0005	.001	.001	.002	.001
Spatially Gen.	.0001	.0005	.001	.001	.002	.001
Street Names						
Spatially Detailed	.0006	.001	.001	.001	.002	.001
Spatially Gen.	.0004	.001	.001	.001	.002	.001
Building Perimeters						
Spatially Detailed	.000	.000	.000	.000	.000	.000
Spatially Gen.	.001	.001	.001	.001	.001	.001
Dining						
Spatially Detailed	.001	.001	.001	.001	.001	.001
Spatially Gen.	.001	.001	.001	.001	.001	.001
Entertainment						
Spatially Detailed	.0004	.0009	.0003	.0007	.0003	.0007
Spatially Gen.	.0003	.0007	.0004	.0009	.0004	.0009
Housing						
Spatially Detailed	.0007	.001	.001	.001	.0008	.001
Spatially Gen.	.0008	.001	.0007	.001	.0008	.001
Key Locales						
Spatially Detailed	.002	.001	.002	.001	.001	.001
Spatially Gen.	.001	.001	.002	.001	.002	.001
Landscape						
Spatially Detailed	.0006	.001	.0006	.001	.0004	.001
Spatially Gen.	.0007	.001	.0004	.002	.0006	.001
Map Features						
Spatially Detailed	.001	.001	.001	.001	.001	.001
Spatially Gen.	.001	.001	.001	.001	.001	.001
Parking						
Spatially Detailed	.0007	.001	.0008	.001	.0007	.001
Spatially Gen.	.0008	.001	.0006	.001	.0008	.001
Scale						
Spatially Detailed	.0007	.001	.0007	.001	.0006	.001
Spatially Gen.	.0005	.001	.0007	.001	.0008	.001
Services						
Spatially Detailed	.0004	.001	.0006	.001	.0004	.001
Spatially Gen.	.0005	.001	.0004	.001	.0006	.001
Transportation						
Spatially Detailed	.001	.001	.001	.001	.001	.001
Spatially Gen.	.001	.001	.001	.001	.001	.001

Table 5. Experiment 2 means and standard deviations as a function of verbal and spatial detail, for all dependent measures and scoring procedures.

	Verbal Detail Condition					
	Full Text		Important Text		No Text	
Measure and Scoring Procedure	*M*	*SD*	*M*	*SD*	*M*	*SD*
Map Drawing						
Category Use						
Spatially Detailed	.26	.13	.51	.23	.80	.31
Spatially Gen.	.22	.24	.40	.28	.78	.33
Buildings Drawn						
Spatially Detailed	.60	.21	.48	.27	.64	.19
Spatially Gen.	.90	.09	.93	.07	.89	.08
Buildings Labeled						
Spatially Detailed	.17	.11	.48	.31	--	--
Spatially Gen.	.23	.05	.87	.20	--	--
Roads Drawn						
Spatially Detailed	.80	.10	.83	.17	.81	.13
Spatially Gen.	.96	.09	.93	.09	.93	.07
Roads Labeled						
Spatially Detailed	.54	.31	.59	.31	--	--
Spatially Gen.	.78	.20	.81	.26	--	--

Figure Captions

Figure 1a-b. An example of spatial and verbal maximizing (a) and minimizing (b) of a college campus map, within the context of a navigational task from Ballou Hall to Psychology Department

Figure 2. Mixing levels of graphic and textual detail in a device displaying geographic information

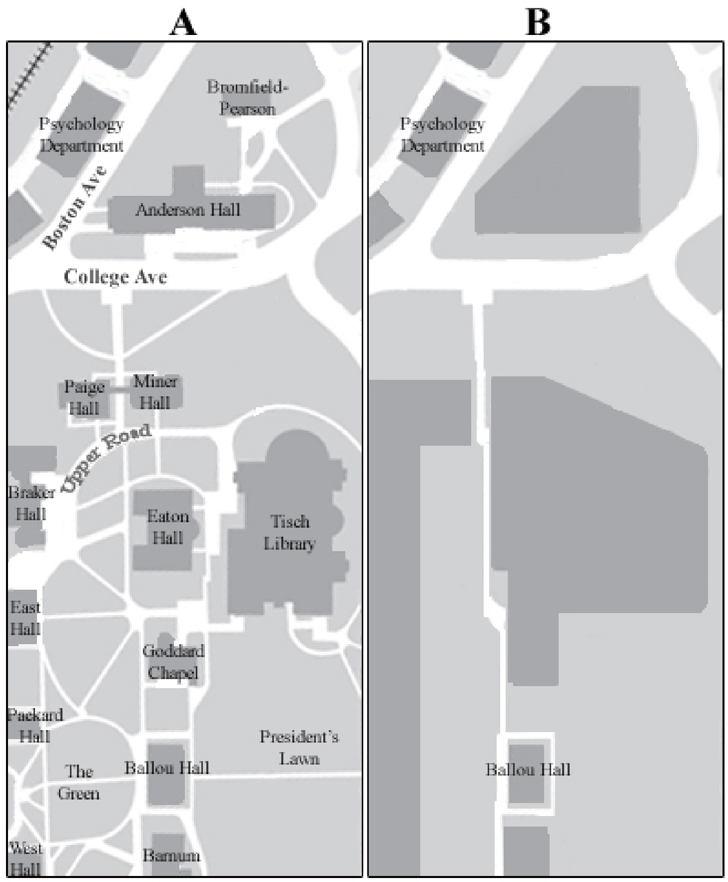
Figure 3. The final adaptation of the Beloit College campus map, in full spatial and verbal detail

Figure 4. The final adaptation of the Beloit College campus map, spatially generalized with full verbal detail.

Figure 5: Proportion of requests for information by request type in Pilot Experiment 1.

Figure 6. An example of a participant-drawn map of Beloit College following study of a map with full spatial and verbal detail.

Figure 7: Proportion of requests for information by request type in Pilot Experiment 2.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B
Bromfield-Pearson
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Boston Ave
Anderson Hall
College Ave
Paige Hall
Miner Hall
Upper Road
Braker Hall
Eaton Hall
Tisch Library
East Hall
Goddard Chapel
Packard Hall
President's Lawn
The Green
Ballou Hall
West Hall
Barnum
Psychology Department
Ballou Hall

Figure 1

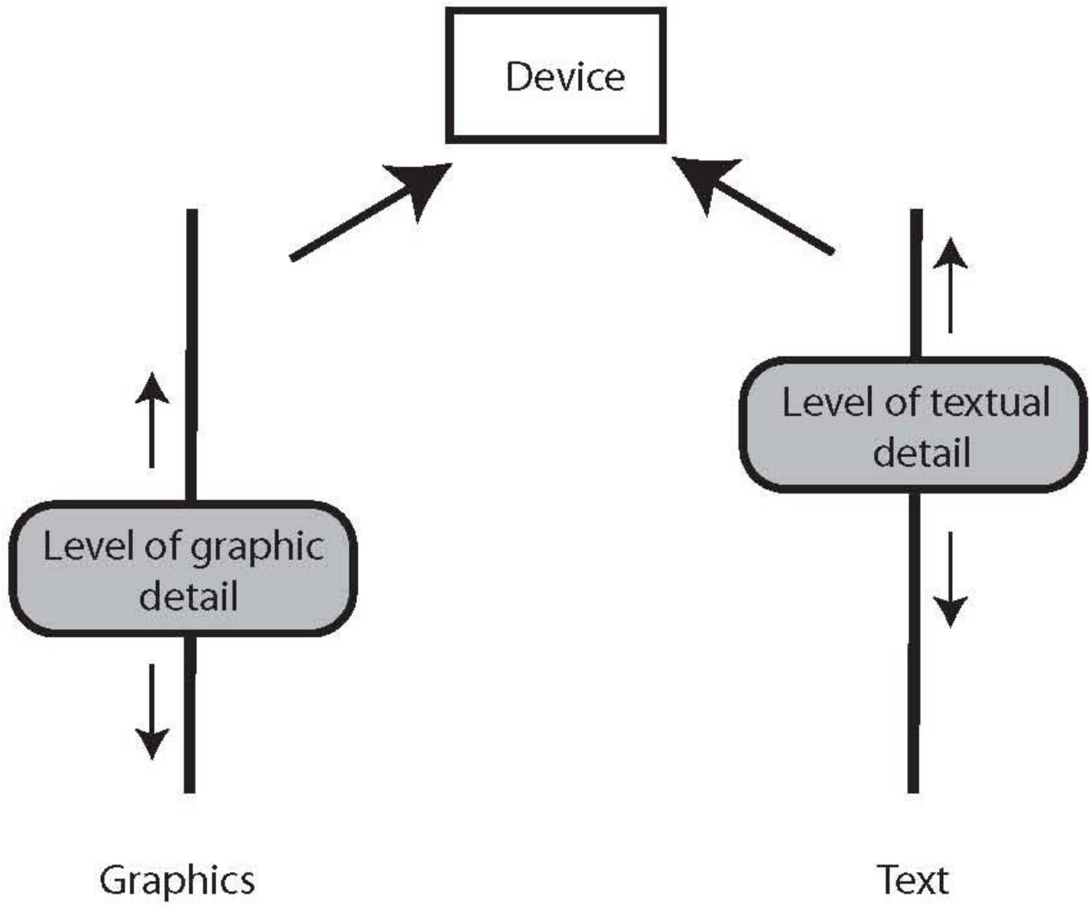

Device
Level of graphic detail
Level of textual detail
Graphics
Text

Figure 2


District Street
Chapin Hall
Emerson Apartments
Maurer Hall
Brannen Hall
Peet Hall
Whitney Hall
Blaisdell Hall
Bushnell Hall
Aldridge Hall
Porter Hall
Clary Street
Tennis Courts
Tau Kappa
Phi Kappa
Flood Arena
Wood Hall
Sigma Chi
Coughy House
Outdoor Club
Alpha Sigma
French House
Theta Pi
Alliance House
College House
Voces Latinas
Career Services
Russian House
Marvin Field House
Haven Hall
College Hall
Emerson Hall
Pleasant Street
College Street
Emerson Street
Church Street
Chamberlin Hall
Morse-Ingersall Hall
Hull Center
Music House
Residence Hall
Mayer Theater
Wood Conservatory
Campbell Hall
Morse Library
Womyn's Center
Physical Plant
Pearsons Hall
Dyson Hall
Human Resources
Spanish House
Eaton Chapel
President's House
Emeritus Offices
International House
Smith Building
Middle College
Chapin Street
World Affairs Center
Admissions Office
South College
Blaisdell House
Public Affairs
Wright Art Hall
Wright Museum
Godfrey Building
Logan Museum
Neese Theater
Bushnell Street
Administration Buildings
Academic Buildings
Theater/Arts Buildings
Residence Buildings
Athletic Buildings

Figure 3

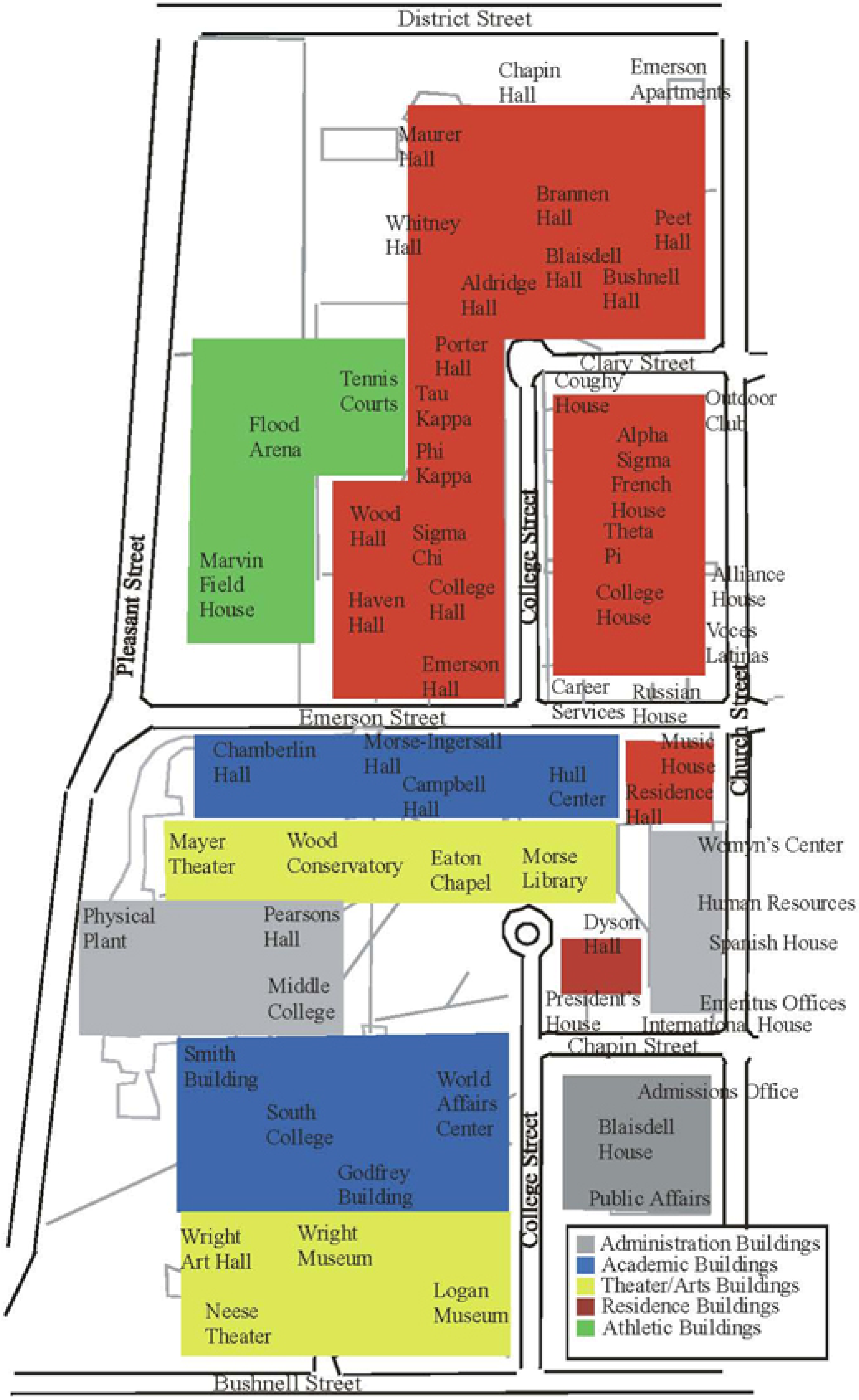
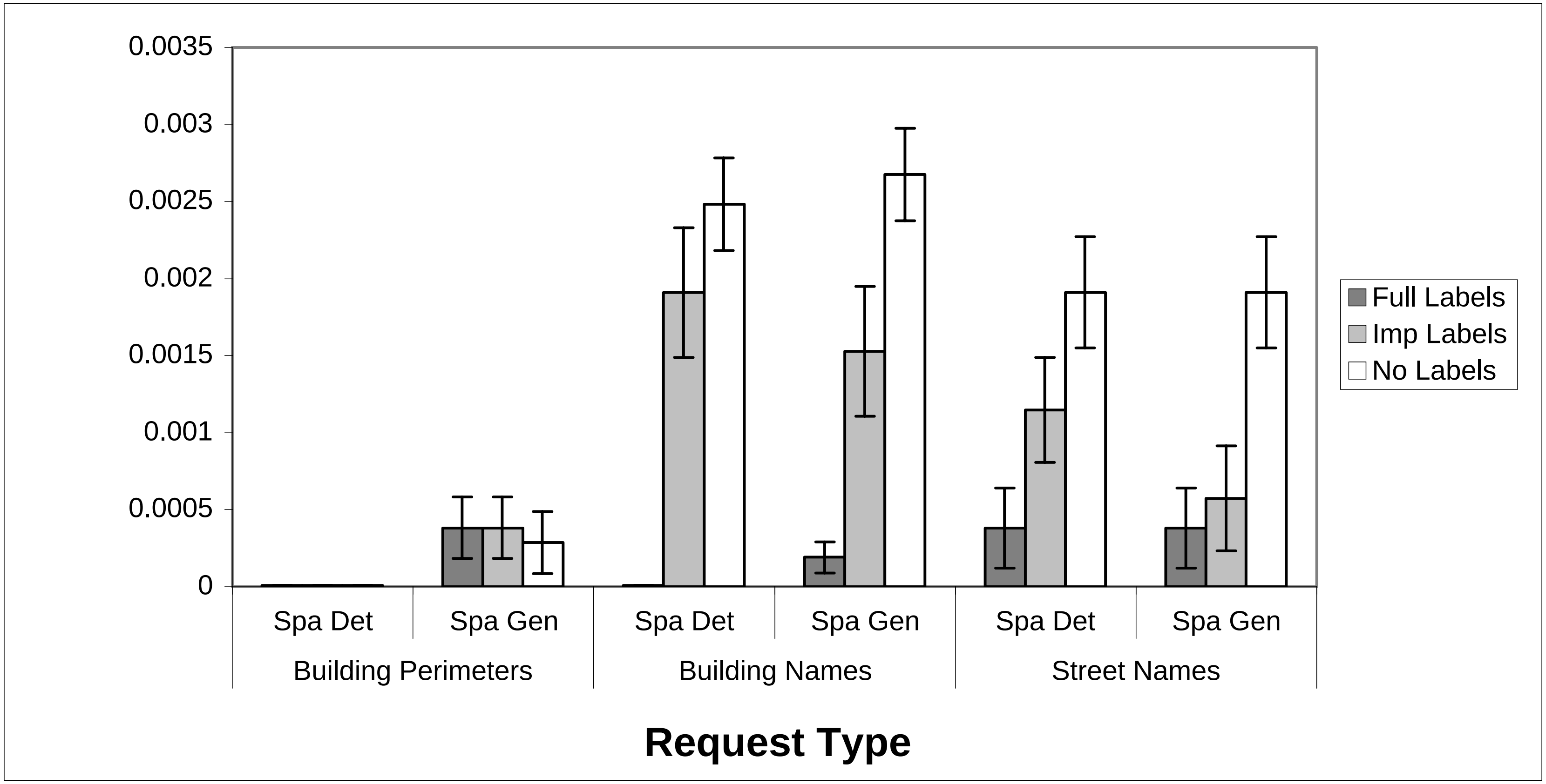

District Street
Chapin Hall
Emerson Apartments
Maurer Hall
Whitney Hall
Brannen Hall
Peet Hall
Blaisdell Hall
Aldridge Hall
Bushnell Hall
Porter Hall
Clary Street
Tennis Courts
Flood Arena
Tau Kappa
Phi Kappa
Coughy House
Outdoor Club
Alpha Sigma
French House
Theta Pi
Wood Hall
Sigma Chi
Marvin Field House
Pleasant Street
College Street
Haven Hall
College Hall
College House
Alliance House
Voces Latinas
Emerson Hall
Career Services
Russian House
Emerson Street
Church Street
Chamberlin Hall
Morse-Ingersall Hall
Campbell Hall
Hull Center
Music House
Residence Hall
Mayer Theater
Wood Conservatory
Eaton Chapel
Morse Library
Womyn's Center
Physical Plant
Pearsons Hall
Dyson Hall
Human Resources
Spanish House
Middle College
President's House
International House
Emeritus Offices
Chapin Street
Smith Building
World Affairs Center
Admissions Office
South College
Blaisdell House
Godfrey Building
Public Affairs
Wright Art Hall
Wright Museum
Logan Museum
Neese Theater
Administration Buildings
Academic Buildings
Theater/Arts Buildings
Residence Buildings
Athletic Buildings
Bushnell Street

Figure 4



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0.003
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Full Labels
Imp Labels
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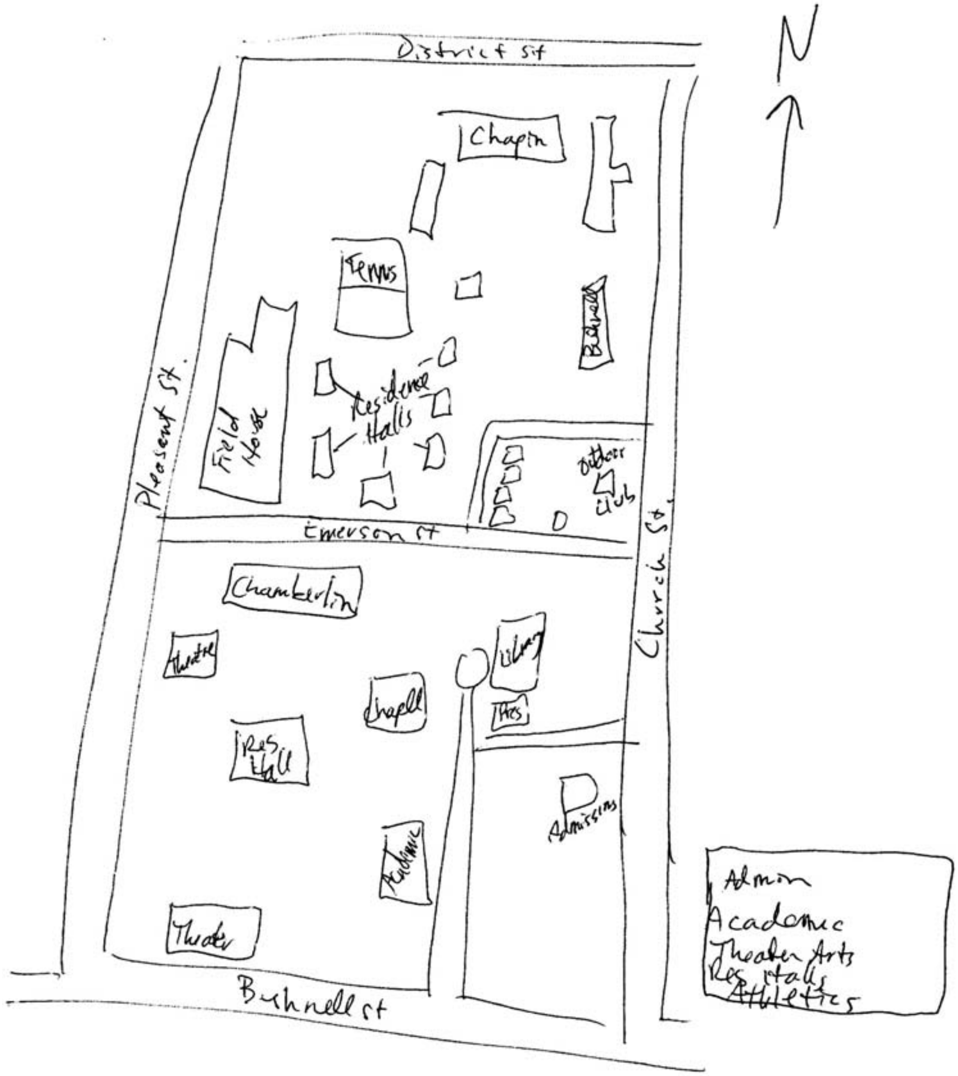
Spa Gen
Spa Det
Spa Gen
Spa Det
Spa Gen
Building Perimeters
Building Names
Street Names
Request Type

Figure 5



N
District St
Chapin
Tennis
Field House
Residence Halls
Pleasent St.
Emerson St
Church St.
Chamberlin
Theatre
Library
Chapel
Res Hall
Admissions
Academic
Theater
Bushnell St
Admin
Academic
Theater Arts
Res Halls
Athletics

Figure 6

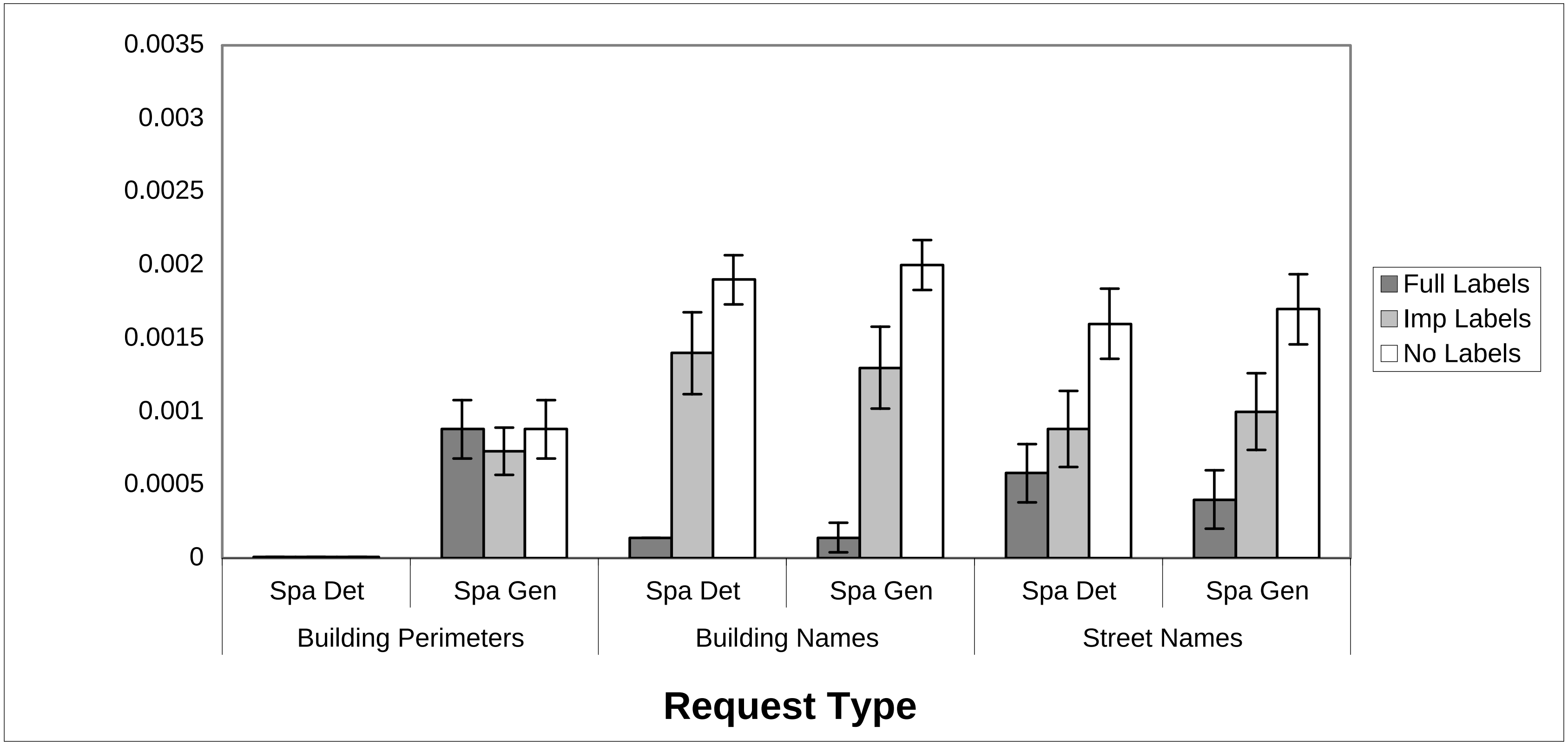

0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
Full Labels
Imp Labels
No Labels
Spa Det
Spa Gen
Spa Det
Spa Gen
Spa Det
Spa Gen
Building Perimeters
Building Names
Street Names
Request Type

Figure 7