Generating Explanatory Captions for Information Graphics

Vibhu O Mittal* Steven Roth Johanna D Moore" Joe Mattis[1] Giuseppe Carenini

Learning Research & Dev Center and
Department of Computer Science
University of Pittsburgh
Pittsburgh PA 15260

Robotics Institute
School of Computer Science
Carnegie-Mellon University
Pittsburgh, PA 15213

Abstract

Graphical presentations can he used to communi cate information in relational data sets succinctly and effectively However novel graphical presen tations about numerous attributes and their relation ships are often difficult to understand completely until explajned Automatically generated graphical presenlations must therefore either be limited to simple conventional ones or risk incornprehen sibility One way of alleviating this problem is to design graphical presentation systems that can work in conjunction with a natural language gener- ator to produce explanatory captions This paper presents three strategies for generating explanatory captions to accompany information graphics based on (1) a representation of the structure of the graph ical presentation (2) a framework for identifying the perceptual complexity of graphical elements and (3)the structure of the data expressed in the graphic We describe an implemented system and illustrate how it is used to generate explanatory captions Ior a range of graphics from a data set about real estate transactions in Pittsburgh

1 Introduction

Graphical presentations can be an effective method for such cinctly communicating information about multiple diverse dala attnbutes and their interrelationships A number of research groups are attempting to develop systems that automatically generate such presentations [Casner 1991 Mackinlay 1986 Roth *el al* 1994] When a display in eludes only a small number of data attributes or only makes use ot conventional graphical styles (e g spreadsheet graph ICS) it is easy for a viewer to understand how to interpret it However one of the main goals for automatic presentation systems is to allow users to see complex relationships between domains and perform problem solving tasks (eg summariz- ing finding correlations or groupings and analyzing trends in dala) that involve many data attributes al the same time These v isualizations are often both novel and complex They can only be fully effective for supporting such analysis tasks if accompanied by explanations designed to enable users to understand how the graphics express the information they contain Furthermore studies (e g [Nugent 1983]) have shown that the presentation of captions with pictures can sig- nificantly improve both recall and comprehension compared to either pictures or captions alone

In this paper we propose a framework for automatically generating explanatory captions to accompany graphical pre sentations of combinations of diverse data sets The graphical displays are designed by an automatic presentation system SAGE [Roth *ft at* 1994] and are often complex for several reasons First they typically display many dala attributes al once The mapping of many different data attnbutes to mul- tiple graphical ob)ects can be difficult to determine from the graphics alone Second integrating multiple datj attnbutes in a display requires designing graphics that are unlamihar to most users accustomed to simple spreadsheet displays ol individual data attributes While these integrated displays can be verv useful once they are explained it is difficult to under stand them completely without accompanying explanations Finally the nature of the data with which we are concerned is inherently abstract and does not have an obvious or natural visual representation Unlike depictions of real world objects or processes (e g radios [Feiner and McKeown 1993] cof fee makers [Wahlsler *el al* 1993] network diagrams [Marks !99lJ) and visualizations of scientific data (eg weather medical images) visualizations of abstract information lack an obvious geometric analog

As an example of the type of data we are concerned with consider the graphic shown in Fig I This is a SAGE generated version ol the famous graphic drawn by Minard in 1861 depicting Napoleon s march of 1812 [Roth *et al* 1994] The graphic relates many different variables position (latitude and longitude) troop size direction of movement temperature and dates and locations of battles Unless one has seen this graphic (or a very similar one) before it cannot be understood and used to its fullest extent

Consider how the following human-generated caption for the graphic in Fig I explains the picture as well as the under lying data

> *This graphic shows march segments and battles from Napoleon 1812 campaign The map shows the relation between the geographic locations temperature and number of troops for each segment Each line show the start and end locations for the march segment Its color[1] shows the: tern*

This work was supported by grant number DAA 15930005 from the Advanced Research Projects Agency (ARPA)

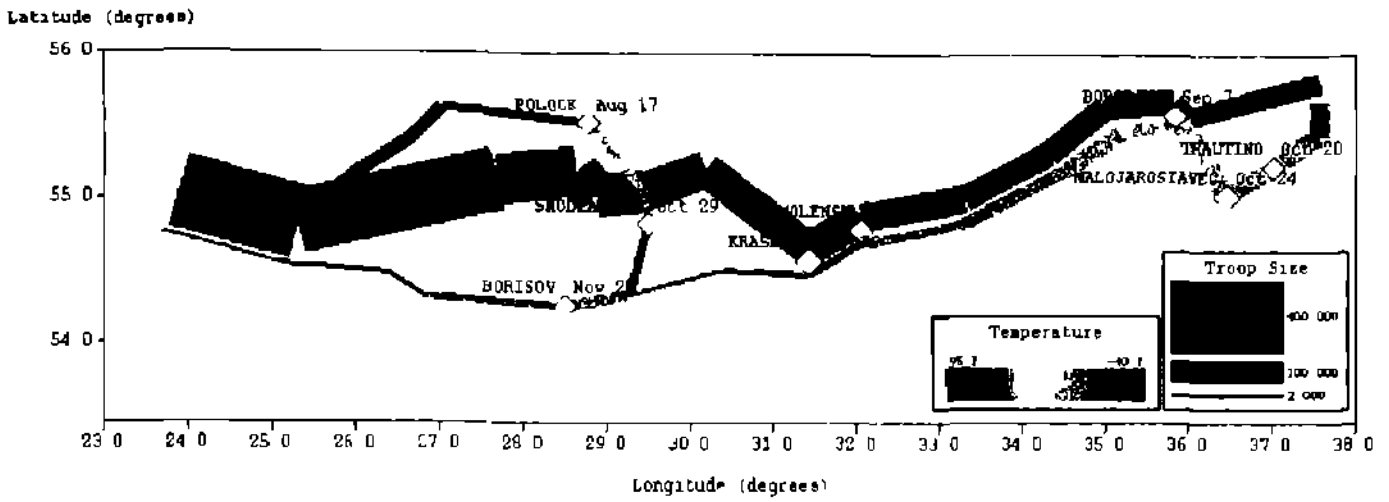


Figure 1 A SAGE generated version of the well known Minard graphic [1]

perature and the thickness shows the number of troops The temperature was about 100 degrees for the initial segments in the west (the wide dark red lines on the left) about 60 degrees in later segments in the east (the narrower light red lines on the right) and about 40 degrees in the last segments also in the west (the narrowest dark blue lines on the left) The number of troops was 400 000 in the earliest segments 100 000 in the later segments and 10 000 in the last segments The city and date of each battle is shown by the labels of a yellow diamond which shows the battle's location

With this caption this complex integrated graphic can be fullv appreciated for the amount of information it conveys so succinetly and clearly

Although several pro)ccls have focused on the question ot how such intelligent graphical presentations can he automatically generated [C asner 199] Mackinlay l486 Roth and Hefley 1993] they have not addressed the problem of generating the accompanying textual explanations In this paper we describe an implemented system designed to gen erate explanatory captions by integrating two robust systems the SAGE intelligent graphics presentation system |Roth *el al* 1994] and a natural language generation framework consist ing ot a text planner [Moore and Paris 1993] and a sentence realizer (Elhadad 1992] This system generates explanatory captions for complex graphical presentations that integrate multiple data attributes by (1) aligning sequences of multi ple charts and lables (2) composing graphical objects (eg points bars lines gauges text strings) within each chart and (3) using multiple graphical properties of each object lo encode data attributes (e g shape color size line thickness ete) This is an important application domain since these types of graphics represent a significant portion of data that must be presented for many business applications [Schmid 1983]

The system selects data to be presented in the caption by taking into account both the characteristics of the data (e g the range and type of attributes as well as the relationships among them) and the way data objects and attributes have been mapped to graphical oh|ects in the presentations generated bv SAGE The system organies is explaninations using one of three explanation strategies and determines how much to say about any individual data lo graphic mapping based on heuristics about the complexity of understanding that particular type of mapping

'SAGE generates color graphics (see [Roth et *al* 1944]) but due to pnnUng limitations grayscale versions arc shown hen-

2 Requirements for Generating Explanatory Captions

Previous efforts in intelligent multimedia presentation have focused on coordinating NI and graphical depictions of real world devices (eg military r idios [Teiner and McKeown 1991] coffee makers [Wahlster *ft al* 1991]) for generating instructions about then repair or proper use In these projLCis researchers have tackled problems such as the apportionment of eonteni to medi land generating cross references Our work differs fiom previous efforts in two wavs First is the type ot data that oui sysiem deals wnh We are concerned with presentations of abstract or relational informalion (e g census reports logistics dalaMlala th u does noi have an obvious or familiar analogy in ihe graphical medium Second although our long term goal is in gcneraling coordinated multimedia explanations using information graphics and natural language our current focus is generating explanatory captions The current system presents all of the d t t i graphically and then generates captions based on the data as well as the perceptual complexity ol the graphic Therelore the graphical display ilsell is the ob)cel ofexplanalion

Generating textual captions for visualizations of abstract or relational information requires the following

- a representation of the *s\nru* of graphical displays that is the structural spatial and other relations among graphical objects and their properties
- a representation of the \emuntu v of graphical displays that is the way they map from data ob|ects and their attributes lo graphical ones
- a mechanism for determining which aspects of graphical displays must be explained based on their perceptual complexity or the complexity of the data attributes they express

- strategies tor generating coherent multi-sentential cap tions

We describe the representations and reasoning strategies we have designed to meet each ot these criteria in the following sections

3 SAGE Overview

SAGF is a know ledge-based presentation system that designs graphical displays of combinations of diverse information (eg quantitative relational temporal hierarchical categor ical geographic) [Roth *et al* 1994] The inputs 10 SAGE include (1) sets of data (2) a characlenzation of the prop ernes of the *data* that are relevant to graphic design (3) a characlenzation of the tasks that the graphics should be designed to support (e g determining the correlation among variables finding subset s of data with extreme VALUES for some attributes and then looking up values of other attributes for these detecting differences between pairs of attributes etc) and (4) an optional set of design specifications expressing a user s preferences for visualizing the data set

SAGE s output consists of one or more coordinated sels of 2D information graphics thai use a variety of graphical techniques lo integrate multiple data attributes in a single display SAGE integrates multiple attributes in three ways First it represents them as different properties of the same set of graphical objects (e g the thickness and shade of line segments in Fig 1) Second it assembles graphical objects into groups that function as units to express data (eg the pair of text strings associated with the diamond shaped marks al different positions on the line segments in Fig 1) Third il coordinates multiple charts and tables by aligning them with respect to a common axis (e g the aligned charts in Figs 2 and 7)

SAGE s representation serves three lunctions in explanation generation It helps define what a viewer must understand about a graphic in order to obtain useful information from it It does this by dehning the elements ot a graphic and the lunclions they serve as they come together lo express facts (i e how they map to data) The representation also describes the structure ol both graphics and the data they present so that they can be explained coherently Finally the representation helps derive judgments of *complexity* for specifying graphical elements needing textual explanation To understand these three functions we briefly review the representation

First SAGE has knowledge of the characteristics ot data relevant lo graphic design [Roth and Mains 1990 Roth and Hefley 1991] including knowledge of data types and scales of measurement (e g quantitative interval or- dinal or nominal data sets) structural relationships among data (e g the relation between the end-points of ranges or between the two coordinates of a 2D geographic location) and the functional dependencies among attributes in database relations (e g one one one many many many etc)

Second SAGE has a library of graphical techniques knowl edge of the appropriateness of the techniques for different data and tasks and design knowledge for assembling these techniques into composites that can integrate information in a single display SAGE uses this graphic design knowledge together with the data characlenzation knowledge to generate displays of information

The portion of SAGE S knowledge base that is most relevanl for generating explanatory captions is its graphical syntax and semanties The syntax includes a definition of the graphical constituents that convey information (e g graphical ob|ects called *graphemes* their properties the frames of reference that enable their properties lo be interpreted/translated back lo dala values) and the ways graphemes can be combined lo form composites that integrate multiple data attributes The syntactic structure ot a graphical display like the linguistic structure of text can provide guidance tor creating structurally coherent explanations

The representation of the *semantie*s of graphics conveys the way data is mapped lo the syntactic elements ot displays It also prov ides guidance for organizing explanatory captions bv grouping graphical elements that express data attributes that form a coherenl group The data characlenzation provides information about the structure of the data and therefore also influences the structure of the explanation

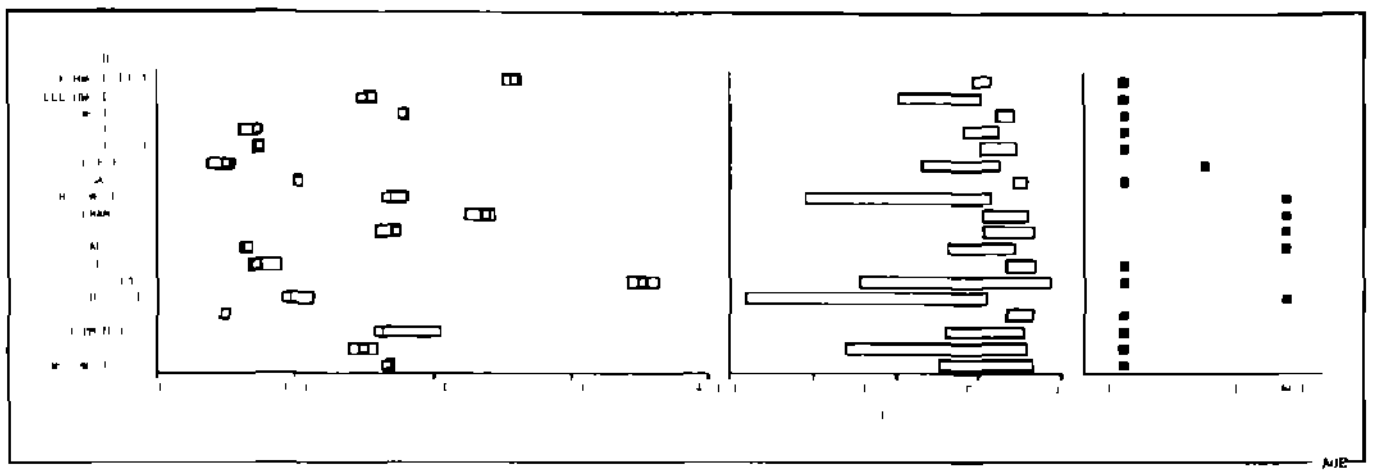
4 Understanding Elements of Graphical Presentations

SAGE S graphics convey assertions about the world that have been represenled as tuples or facts in a relational database In the example data set used here the assertions are facts from a relational database of house sales (e g street address date placed on market date sold asking and selling prices agency estimate ol selling price listing agency number ol rooms etc) These are expressed bv mapping them to graphical assertions which are collections of graphemes and their properties

Understanding a graphic is a process ot determining how data attributes are related to graphical techniques (e g color shape horizontal and vertical position) This mapping is usually given by axes or keys which are called encoders (because they encode dala values into graphical values) En coders provide a frame ol reference so that one can convert between values of graphic techniques (e g blue horizon- tal pixel location 120) and data values (eg Century-21 $10 000) Knowing how a data attribute is expressed also requires knowing the graphical ob|ecl 0 e the grapheme) that is mapped lo it For example in Fig 2 it is not only necessary lo know that prices are expressed with respect lo the horizontal axis but also that each bat grapheme expresses the asking and selling prices while the square grapheme expresses the agency estimate Even more precisely we need to know the properties of these graphemes that are mapped to the attributes the horizontal position ot the left and right edges ot each bar convey selling and asking pnces while the horizontal position of the geometric center ol each square conveys agency estimate

Understanding a graphic may also require determining which graphemes and properties function together as units to express semantically coherenl groups of attributes For example in Fig 5 the shade vertical position and horizontal positions of the edges of each bar combine with the mark graphemes to convey five data attributes

To summarize SAGE S representation defines components of graphics that must be understood for one to interpret how a graphic conveys information In order to understand how a graphical technique is used one must locale and understand the encoders that are frames of reference for convening



(1) These three charts show information about houses from data set PGH 23 (2) The Y axis identifies the houses in the three charts (3) In the left chart house prices are shown by the X axis (4) The house's selling price is shown by the left edge of a bar (5) whereas the house's asking price is shown by the right edge of the bar (6) The horizontal position of the square mark shows the house's agency estimate (7) For example the asking price of 1950 Beechwood is $175K (8) its selling price is $165K and (9) the agency estimate is $164K (10) In the middle chart the house's date on the market is shown by the left edge of a bar whereas (11) date sold is shown by the right edge of the bar (12) The right chart shows the house's listing agency

Figure 2 Graphic with caption generated using strategy 1

graphical values for that technique into data values One must also identify the graphemes and their properties that represent particular data attributes with respect to the encoder techniques and the clusters of graphers that tome together as units to express multiple attributes

5 Graphical Complexity The Need for Clanfication

While the represent ition identities all the elements that one must understand to interpret i graphic generating explana lions requires focusing only on those elements that are not apparent Indeed an explanation that includes all the ele ments needed lo understand a graphic would he extremely verbose Therelore it is necessary fot SAGE to identity those elements that might be difficult for a viewer understand in answering lhe question What data attributes are shown and how are they expressed i n the graphic'

There are five types of complexity that can make it difficult for a user to answer this question and they correspond lo graphical elements discussed previously

• Encoding technique complexity One factor that deter mines the difficulty of undersianding encoding techniques is the number of dimensions involved For example in fig 1 saturation and color[2] are combined in a single encoding tech nique to express temperature Dark red indicates 100 degrees and dark blue indicates 40 degrees As the color gets paler (less saturated) it indicates a less extreme temperature For example pale red (pink) indicates 6S degrees while pale blue indicates S degrees White indtcales a special transition point (e g 32 degrees)

Another example of technique-encoder complexity is the use of truncated scales for quantitative allnbules For exam- ple the X axis in Figure S does not have iero ongins so the d ila can he distributed across a wider area Therefore M is erroneous lo conclude th H a point that is twice the distance from lhe on gin is another point encodes a value twice as large as the tirsi one This is a common occurrence in charts so n is unlikely to be misinterpreted However this error can occur in less Jamihar techniques (e g the *.IKA* of circles eic) as well

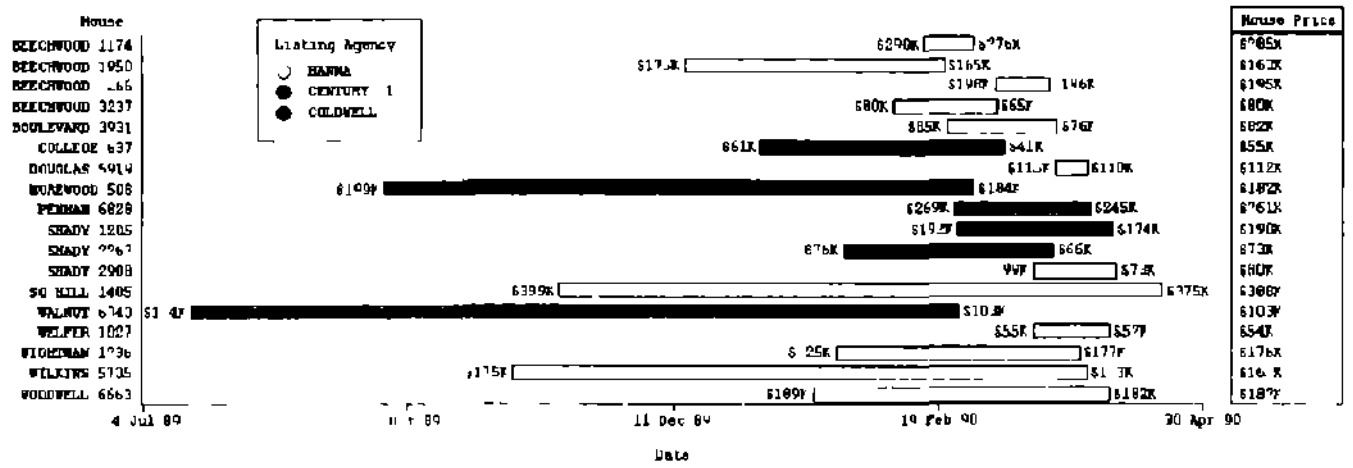
• Grapheme complexity Although the technique and en coder may be simple it is possible thai a grapheme thai uses that technique and encoder is geometrically complex and so it is difficult to determine how it should be interpreted with respect lo lhe encoder/technique For example while the axis in Lhe middle chart of Fig 2 is simple lo interpret the interval bars are complex if one has never seen them Unlike the simple marks (squares) in the nghtmosl chart the parts of the bar thai map to the axis are the left and right edges Similar problems occur tor other types of graphemes (like the lines in Fig 1)

• Multiple grapheme properties A user s abilitv to identify the mapping of even simple techniques can be hindered when multiple properties of a grapheme are used al one time (e g shape color and size of a point in a chart) For instance it may not be clear that both the left and right edges ot the horizontal interval bars in Fig 2 map lo different domains Or that two similar graphemes may map lo very different domains for instance in Fig I lhe two text graphemes (the labels next to the diamonds) map lo battle-sites and dates respectively It is also possible that some properties can be overlooked because others are more salienl For inslance if all the housts in the data set in Fig 5 were listed by the same agency then all the interval bars would be the same shade In such a case the fact that the shade of the bar is used lo communicate a data value could be overlooked

• Multiple graphemes When multiple graphemes occur in a space they can be confusing at first until their relation

In this grayscale version though the colors cannot be seen the variation in saturation can be observed

Spaces arc groupings ol graphical elements that arc positioned



This chart and table show information about house sales from data set PGH 23 The Y axis identifies the houses in the two spaces In the chart dates are shown along the X axis The house s date on the market is shown by the left edge of a bar whereas the house s date sold is shown by the right edge of the bar The shade indicates the listing agency The label to the left of a bar indicates the asking price of a house whereas the label to the right of a bar indicates the selling price For example the asking price of 6343 Walnut is $124k its selling price is $103K its date on the market is August 10th and the date sold is Feb 20th The table shows the agency estimate

Figure 3 Caption for an alternative presentation of the dataset used in Figure 2

to each other is understood by the viewer For example in the leftmost chart of Fig 2 one must recognize the relation between the square and the bars i e that the horizontal positions of the squares and the edges of the bars are all relevant (and related) Our current framework categorizes multiple graphemes to be either cooperating or *interfering* based on their position and effects on the user For instance the mark and the horizontal bar in Fig 2 are considered interfering whereas the labels and the mark in Fig 1 are considered cooperating

• Complex alignments As illustrated in Figs 2 3 and 7 alignment can be a useful technique for supporting compar isons rapid lookups tor many attributes of the same ob|ect and for maintaining consistent scales Whenever an alignment of multiple charts and/or tables occurs all but one become separated from the axis label and the relation between the aligned axis and all the charts may not be obv IOUS

The primary function of an explanatory caption is to make it easier for a user lo determine the data that ihe graphic contains and how the data is expressed Understanding the latter requires identifying the property of the grapheme (e g left edge of a bar) and its relation lo the encoding technique (eg position along an axis) Therefore for each data attribute an explanation must describe those elements of the picture that are complex The complexity assessment module identifies the graphical elements that require clarification in the caption For example the result of the complexity assessment module for the graphic in Fig 2 is shown in Fig 4 (the t after multiple graphemes is to indicate that these are *interfering)*

6 Generating Explanatory Captions

To generate explanatory captions we use a natural language generation system consisting of a text planner [Moore and

according to a single layout discipline e g charts maps networks tables etc

Data attribute	Graphical Element	Complexity Type
house	axis	alignment complexity
asking price	grapheme property	complex grapheme multiple properties multiple graphemes (n)
selling price	grapheme property	complex grapheme multiple properties multiple graphemes (n)
agency estimate	grapheme	multiple graphemes (n)
date on market	grapheme property	complex grapheme
date sold	grapheme property	complex grapheme
listing agency		

Figure 4 Complexity assessment for Fig 2

Paris 1993] and a sentence realizer [Elhadad 1992] The system s knowledge about how to produce explanatory captions is encoded into plan operators and control strategies for the text planner The operators can be viewed as recipes for achieving a given explanatory goal Two of the plan operators used by the system are shown in Fig 6 Each operator specifies the constraints under which the steps in the operator can achieve the specified effect Constraints refer to knowledge sources to find information to include in the explanation and to check the appropriateness of a given strategy Thev may refer to the SAGE representation of a picture the complexity Inlorrnation the user model and the context created by the dialogue (including the evolving text plan) Here we confine our discussion of the text planner to how it is used in generating explanatory captions For a more complete discussion of the text planner see [Moore 1995 Moore and Pans 1993]

To generate a caption the system passes a goal of the form (DESCRIBE (GRAPHICAL-MAPPINGS (PICTURE

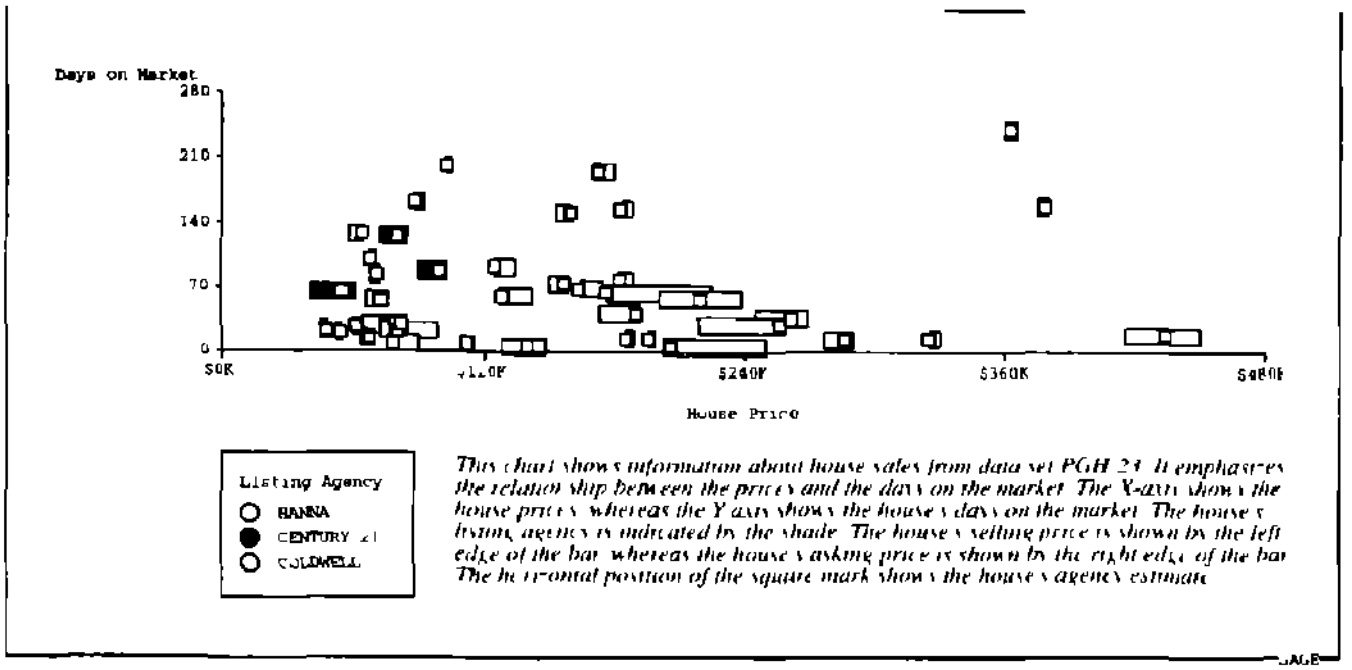


Figure 5 Graphic with caption generated using strategy 2

"PICTURE)))[4] to the text planner The planner then finds all operators capable of achieving this goal in the current context Once a strategy is selected it may in turn post subgoals for the planner to retine I or example the operator shown in Fig. 6 posts several subgoals depending on the number of bindings for the variable ?space in the FORALL construct Planning continues bv running subgoals in this fashion until the entire plan is retined into primitive actions that can be directly executed (in this case speech acts such as INFORM) Once a text plan is completed it is recorded in the dialogue history and passed to the realization component For each speech act in the text plan the realization compo nent performs lexical choice constructs appropriate referring expressions using the algorithm proposed by Dale (1992) and selects passive vs active forms to ensure local coherence based on the centering framework of Grosz *et al* (199S) The resulting lexico syntactic structures are then aggregated into complex sentences and passed to the syntactic realiza tion grammar of the FUF system [Elhadad 1992] which then generates the English text

```
(define-text-plan-operator
    name generate-caption-strategy 1
    effect (describe (graphical-mappings (picture ?picture)))
    constraints
       ((depicts-dataset ?picture ?dataset)
        (independent-domain ?dataset ?indep)
        (anchor ?indep ?picture)
        (all spaces ?picture ?spaces)
        (> (number ?spaces) 1))
    steps ((identify (depicts-indep ?picture ?indep ?dataset))
           (describe (anchor-mapping ?picture ?indep))
           (FOR ALL ?space in ?spaces
              (describe (anchored-graphical-mappings
                 ?space ?indep))))

(define-text-plan-operator
    name describe-grapheme
    effect (describe (grapheme ?grapheme) (space ?space))
    constraints
       ((grapheme? ?grapheme)
        (get-properties-mapped ?grapheme ?space ?properties)
        (> (number ?properties) 2))
    steps (FOR ALL ?property in ?properties
             (describe (property ?property)
                (grapheme ?grapheme) ?space)))
```

Figure 6 Sample Plan Operators

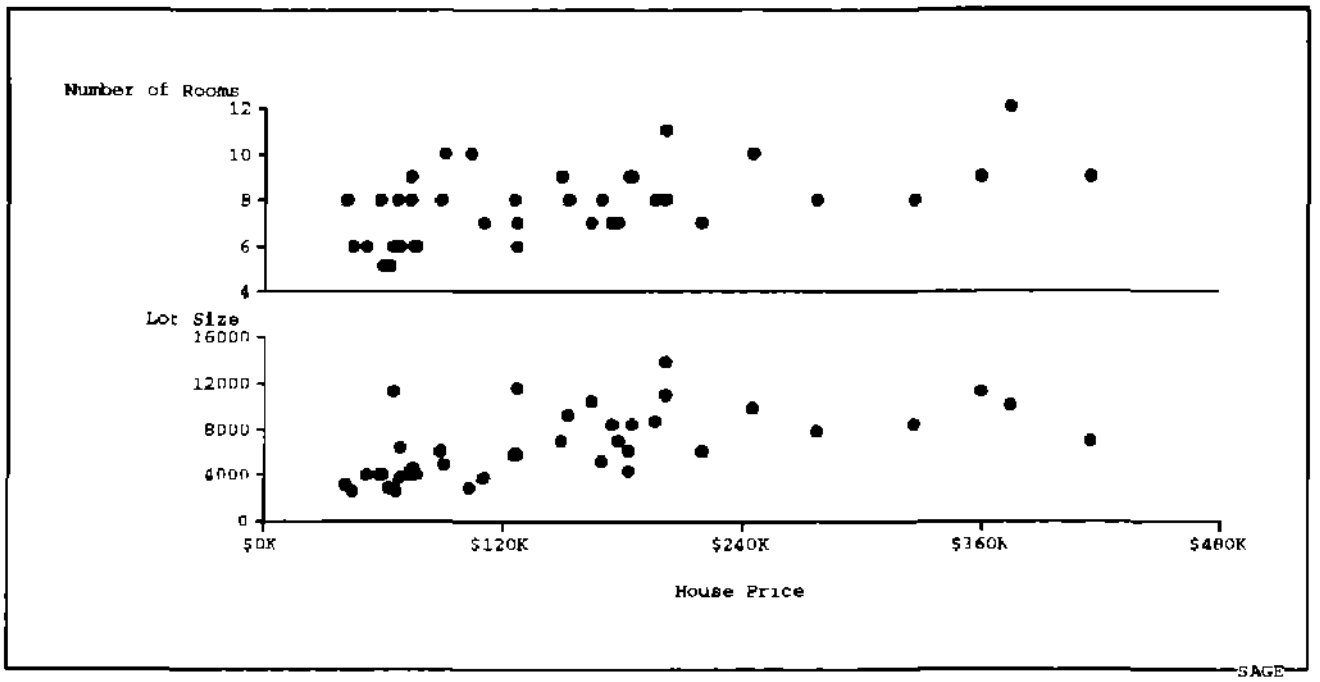
6 1 Strategies for Generating Captions

Explanations about information graphics can be classified into at least three calegones based on (he structural properties of the picture as well as the structure of the underlying data attributes and their mapping to spaces and graphemes These explanation strategies reflect the overall structure of the graphic presentation the spaces are described left to right and within each space the explanation proceeds from the graphical clusters to the individual graphemes In addition to these factors the choice of explanation strategy also depends upon whether the spaces are aligned along a common axis and around the functionally independent attribute An attribute is functionally independenl of il uniquely determines the values of all other attributes For example the house s street address uniquely determines the asking price selling price and so on In contrast the listing agency does not uniquely determine any of the other attributes in the relation In our current system an explanation strategy is selected as described below

Graphic organized around the functionally independent attribute

Strategy 1 The first strategy is chosen when the data set contains a functionally independent attribute that is used as an organizing device or anchor for the entire graphic This strategy applies when the graphic has only one space and the independent attribute is along one of the axes or when there

[4]The actual syntacue form used lo represent the goals and speech acts in the implemented system is more complex fur the sake of clarity we have shown simplified versions in this paper



These charts show information about house sales from data set PGH 23 In the two charts the X axis shows the selling prices The top chart emphasizes the relationship between the number of rooms and the selling price The bottom chart emphasizes the relationship between the lot size and the selling price

Figure 7 Graphic with caption generated using strategy 3

are multiple spaces and the independent attribute is mapped to the axis of alignment

In this case the explanation should reinforce the organizing role of the functionally independent attribute One of the plan operators that implements this strategy is shown in Fig 6 The first step in the body of this operator posts a subgoal to identify the data that is depicted in this picture as data about the independent attribute in a particular dataset The second step posts a subgoal to describe the graphical structure that is the anchor and identify the independent attribute as being expressed by the anchor The third step causes the planner to post a subgoal to describe each space in the picture relative to the anchor A SAGE generated graphic and the associated explanation that illustrates this organizing principle is shown in Fig 2 We go through this explanation in detail in the next section

Graphic organized around dependent attributes

In cases where the graphic is organized around dependent attributes the explanation cannot be structured around any of them Instead the explanation emphasizes the *relation* between the dependent attribute(s) that serve as organizers) There are two strategies depending on whether *or* not the figure consists of multiple spaces

- Strategy 2 When there is only a single space in the graphic the explanation should emphasize the relation between the attributes encoded against the axes A SAGE generated graphic and the associated explanation that illustrates this organizing principle is shown in Fig 5
- Strategy 3 If the graphic has multiple spaces and the axis of alignment encodes a dependent attribute the explanation must describe each space independently using the appropriate strategy tor each space That is if a space is anchored on an independent attribute use the strategy for describing anchored spaces Otherwise use the strategy for describing a space in which dependent attributes are expressed on the axes Fig 7 shows such a graphic and the corresponding explanation

6.2 A Detailed Example

Now we consider in detail how our system generates the caption for the graphic in Fig 2 This graphic consists of multiple spaces aligned with respect to an axis expressing a functionally independent data attribute Therefore the plan operator for strategy 1 shown in Fig 6 is chosen The first step of this operator posts a subgoal to identify the data that is depicted in this picture as data about the independent attribute (here house) in a particular dataset (PGH-23) Satisfying this goal leads to sentence (1) in the caption

The operator s second step posts a subgoal to describe the graphical structure that serves as the anchor for the three spaces and identifies the independent attribute (house") as being expressed by the anchor (the Y-axis) This generates sentence (2) The clause in the three charts is included when describing the house attribute because the complexity assessment module indicated that this attribute is complex due to the alignment

The third step causes the planner to post subgoals to describe each of the three spaces in the picture relative to the anchor i e the Y-axis Clauses (3) describe the first space i e the left chart Within the first space there are two sets of graphemes bars and square marks

The operator for describing anchored spaces finds all of the attributes expressed in the space and groups those that have complexities by the grapheme that expresses them. The strategy for describing how an attribute is expressed depends on the types of complexity that exist for that attribute. As shown in Section 5, selling price and asking price were both associated with a complex grapheme. Clauses (4) and (5) clarify the mapping of these attributes to properties of the associated grapheme, i.e., the bar. In contrast, the agency estimate is rated complex solely because there are other graphemes in the same space, and therefore clause (6) simply identifies the square mark as the grapheme that expresses it.

Clauses (7)–(9) give examples of the attributes selling price, asking price, and agency estimate. The strategy for clarifying the mapping of attributes to properties of the associated grapheme includes an optional step of giving examples. This optional step is expanded if the attribute has complexity of type complex grapheme, multiple graphemes, or encoding technique complexity, unless this type of complexity was exemplified for a previous attribute (as recorded in the evolving text plan). As a result, the description of the second space's attributes in clauses (10)–(11) does not include examples.

Finally, because there are no complexities associated with listing agency, and it is the only attribute expressed in the third space other than house (the anchoring independent attribute), clause (12) simply states that the chart expresses the attribute.

Notice that the caption generated for the graphic in Figure 3 differs from the caption in Figure 2, even though the dataset used for generating the graphics is the same. This is because the explanation reflects the different ways in which the graphic expresses the data in the two figures.

7 Conclusions and Future Work

The ability to generate captions to explain novel or creative information graphics is crucial for understanding how they express data. In this paper, we presented a general purpose method for generating explanatory captions for information graphics that employ a variety of graphical techniques to integrate multiple data attributes in a single display. The system generates captions based on: (1) a representation of the structure of the graphical presentation and its mapping to the data it depicts, (2) a framework for identifying the perceptual complexity of graphical elements, and (3) the structure of the data expressed in the graphic.

There are two parts to effectively using a graphic: (1) understanding how the graphic expresses its data, and (2) understanding how to use the graphic for a particular task. Thus far, we have addressed the first issue. Since a graphic may be used to support multiple tasks, the usefulness of explanatory captions would be increased if they included instructions for how to use the graphic for a given purpose. We plan to address this issue in future work.

Acknowledgments We gratefully acknowledge John Kolojejchick's invaluable help in preparing the figures for this paper.

References

[Casner 1991] Steven Casner. A task-analytic approach to the automated design of graphic presentations. *ACM Transactions on Graphics*, 10(2):111–151, April 1991.

[Dale 1992] Robert Dale. *Generating Referring Expressions*. ACL-MIT Series in Natural Language Processing. The MIT Press, 1992.

[Elhadad 1992] Michael Elhadad. *Using Argumentation to Control Lexical Choice: A Functional Unification Implementation*. PhD thesis, Columbia Univ., New York, NY, 1992.

[Feiner and McKeown 1993] Steven K. Feiner and Kathleen R. McKeown. Automating the Generation of Coordinated Multimedia Explanations. In Maybury [1993], pages 117–138.

[Grosz *et al.* 1995] Barbara J. Grosz, Aravind K. Joshi, and Scott Weinstein. Centering: A Framework for Modelling the Local Coherence of Discourse. TR 95-01, IRCS, Univ. of Pennsylvania, Jan. 1995.

[Mackinlay 1986] Jock D. Mackinlay. Automating the design of graphical presentations of relational information. *ACM Transactions on Graphics*, 5(2):110–141, April 1986.

[Marks 1991] J. Marks. *Automating the Design of Network Diagrams*. PhD thesis, Harvard Univ., Dept. of Computer Science, 1991.

[Maybury 1993] Mark T. Maybury, editor. *Intelligent Multimedia Interfaces*. MIT Press, Menlo Park, CA, 1993.

[Moore and Paris 1993] Johanna D. Moore and Cécile L. Paris. Planning Text for Advisory Dialogues: Capturing Intentional and Rhetorical Information. *Computational Linguistics*, 19(4):651–694, December 1993.

[Moore 1995] Johanna D. Moore. *Participating in Explanatory Dialogues: Interpreting and Responding to Questions in Context*. MIT Press, Cambridge, MA, 1995.

[Nugent 1983] Gwen C. Nugent. Deaf students' learning from captioned instruction: The relationship between the visual and caption display. *Journal of Special Education*, 17(2):227–234, 1983.

[Roth and Hefley 1993] Steven F. Roth and William E. Hefley. Intelligent Multimedia Presentation Systems: Research and Principles. In Maybury [1993], pages 13–58.

[Roth and Mattis 1990] Steven F. Roth and Joe Mattis. Data characterization for intelligent graphics presentation. In *Proc. CHI '90*, pages 193–200, New Orleans, LA, 1990. ACM/SIGCHI.

[Roth *et al.* 1994] Steven F. Roth, John Kolojejchick, Joe Mattis, and Jade Goldstein. Interactive graphic design using automatic presentation knowledge. In *Proc. CHI '94*, Boston, MA, 1994. ACM/SIGCHI.

[Schmid 1983] Calvin F. Schmid. *Statistical Graphics: Design Principles and Practices*. John Wiley and Sons, 1983.

[Wahlster *et al.* 1993] Wolfgang Wahlster, Elisabeth Andre, W. Finkler, H.-J. Profitlich, and Thomas Rist. Plan-based integration of natural-language and graphics generation. *Artificial Intelligence*, 63(1-2):387–427, October 1993.