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Allen et al.

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[45] Date of Patent: Dec. 3, 1996

[54] **CASE-BASED REASONING SYSTEM**

[75] Inventors: **Bradley P. Allen**, Hermosa Beach; **S. Daniel Lee**, San Gabriel, both of Calif.

[73] Assignee: **Inference Corporation**, Novato, Calif.

[21] Appl. No.: **247,630**

[22] Filed: **May 23, 1994**

Related U.S. Application Data

[63] Continuation of Ser. No. 664,561, Mar. 4, 1991, abandoned.

[51] **Int. Cl.**[6] **G06F 15/18**

[52] **U.S. Cl.** **395/51**; 395/12; 395/77

[58] **Field of Search** 395/77, 51, 12

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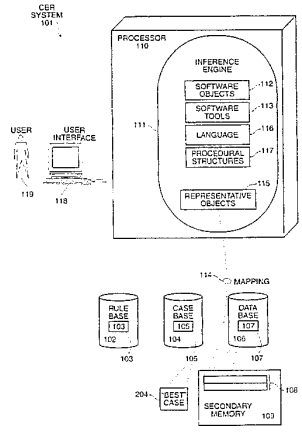
[57] **ABSTRACT**

A case-based reasoning system which is smoothly integrated into a rule-based reasoning system, thus coordinating case-based reasoning techniques and rule-based reasoning techniques in a unified automated reasoning system, in which an automated processor may proceed by inferential reasoning on the facts of the problem and the cases by means of rule-based reasoning techniques or based on procedural directives supplied by a human programmer, and may select the case which is the best match for the problem, but may act differently from the precise action prescribed for that case. A technique for dynamically adapting the case base to the problems which the automated reasoning system encounters, in which the processor may create additional cases which may exemplify the problem or which may be useful for future problems, or may remove cases from the case base which it determines from experience are poor or obsolete. A technique in which the processor may be set to work with a limited case base, and may solicit human advice for treatment of new problems which are not already well-treated by the case base.

38 Claims, 12 Drawing Sheets



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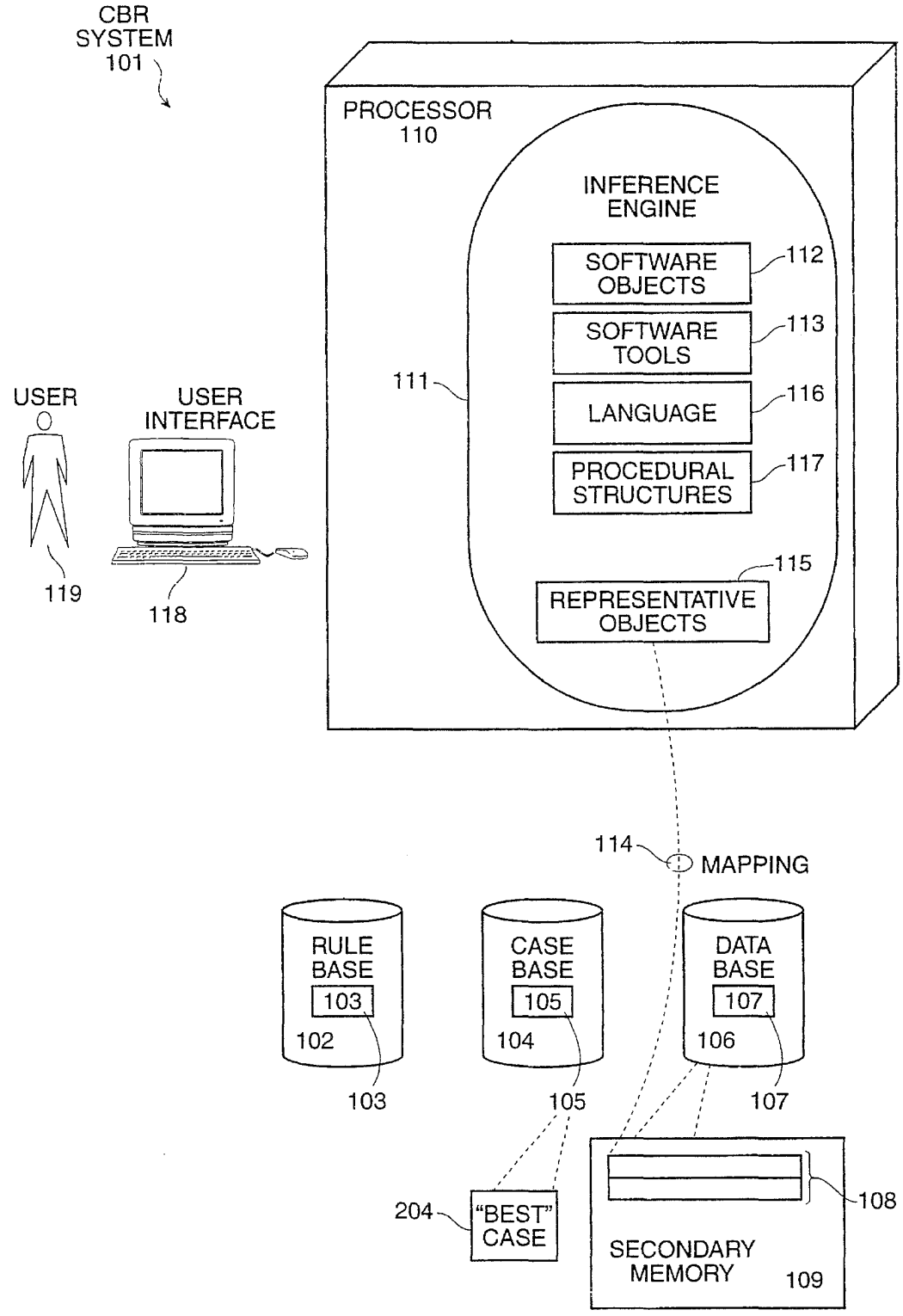
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PROCESSOR 110
INFERENCE ENGINE
SOFTWARE OBJECTS
112
SOFTWARE TOOLS
113
LANGUAGE
116
PROCEDURAL STRUCTURES
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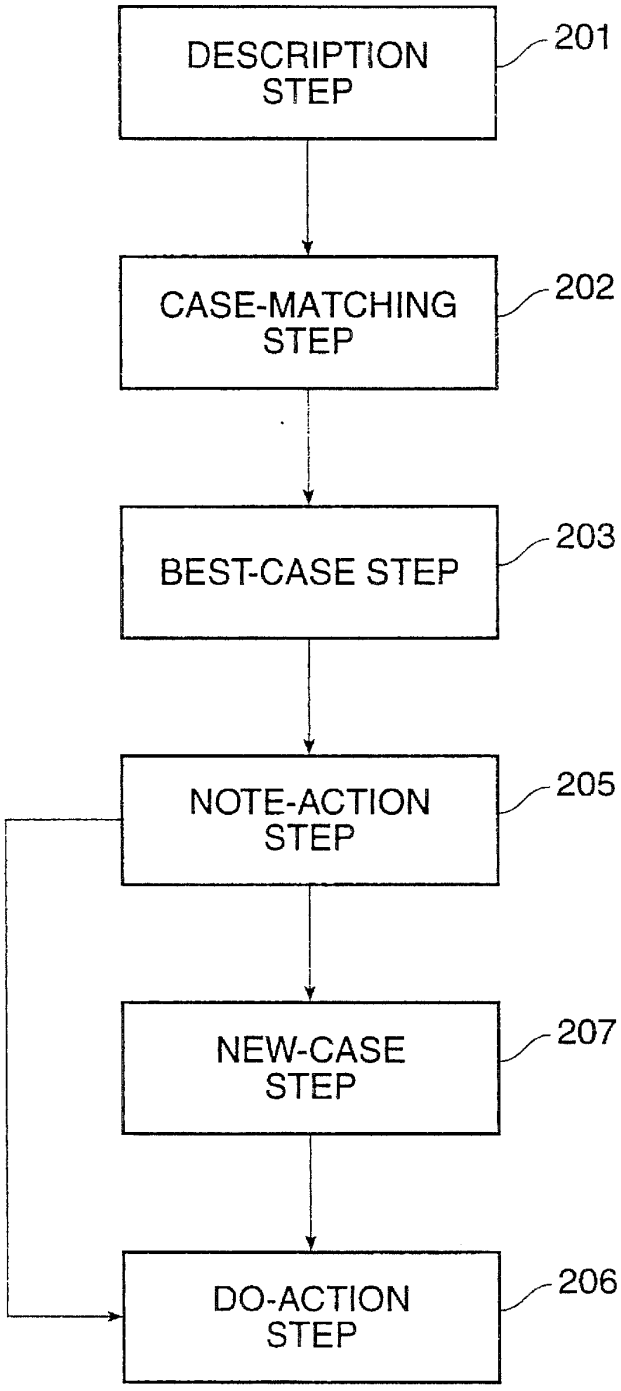
111
REPRESENTATIVE OBJECTS
115
USER
USER INTERFACE
119
118
114
MAPPING
RULE BASE
103
102
CASE BASE
105
104
DATA BASE
107
106
103
105
107
204
"BEST" CASE
108
SECONDARY MEMORY
109

FIG. 1


DESCRIPTION STEP
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CASE-MATCHING STEP
202
BEST-CASE STEP
203
NOTE-ACTION STEP
205
NEW-CASE STEP
207
DO-ACTION STEP
206

FIG. 2

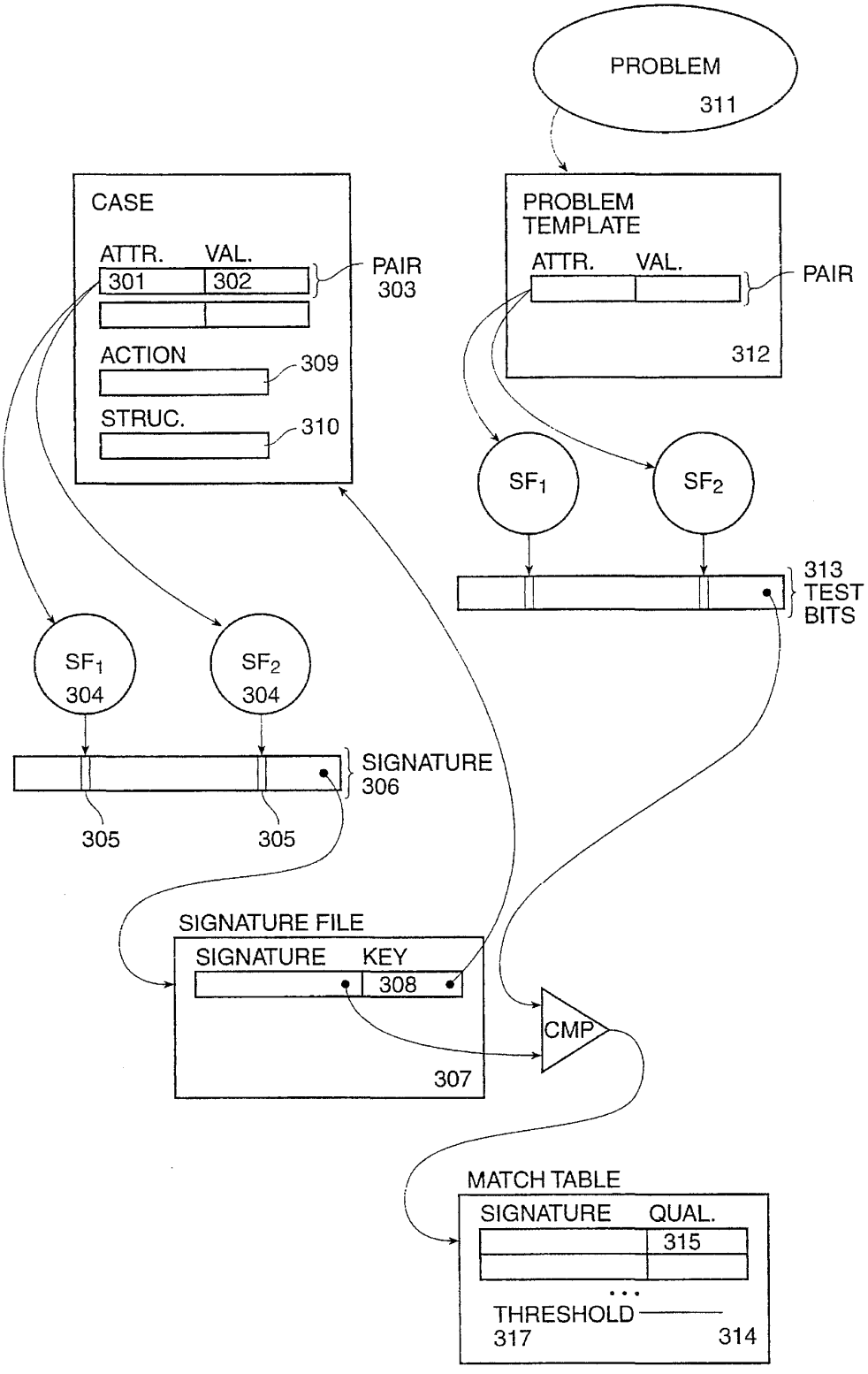

PROBLEM
311
CASE
ATTR.
VAL.
301
302
PAIR
303
ACTION
309
STRUC.
310
PROBLEM
TEMPLATE
ATTR.
VAL.
PAIR
312
SF1
SF2
313
TEST
BITS
SF1
304
SF2
304
SIGNATURE
306
305
305
SIGNATURE FILE
SIGNATURE
KEY
308
307
CMP
MATCH TABLE
SIGNATURE
QUAL.
315
THRESHOLD
317
314

FIG. 3A

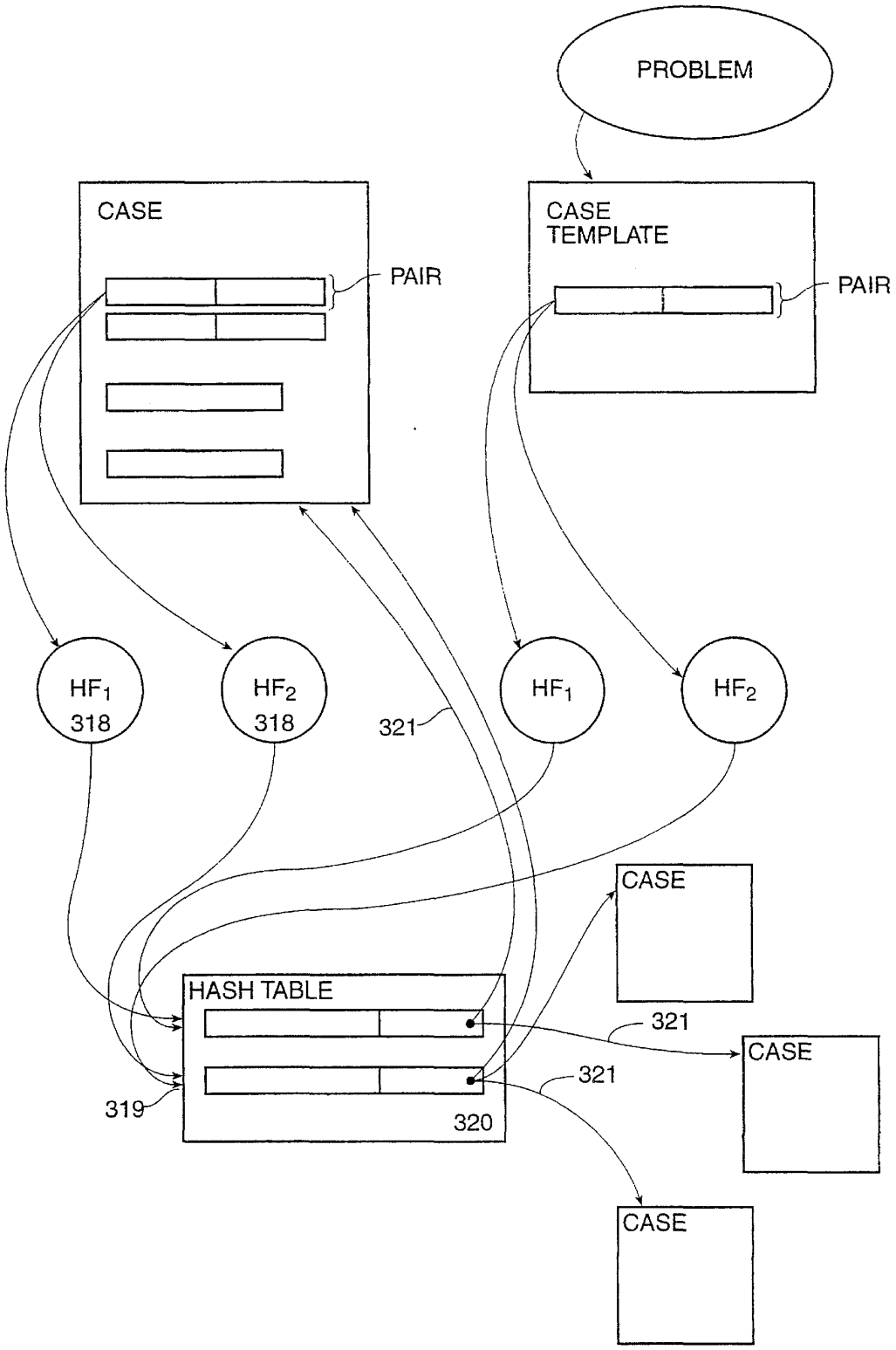

PROBLEM
CASE
PAIR
CASE TEMPLATE
PAIR
HF1 318
HF2 318
321
HF1
HF2
CASE
HASH TABLE
321
CASE
321
319
320
CASE

FIG. 3B

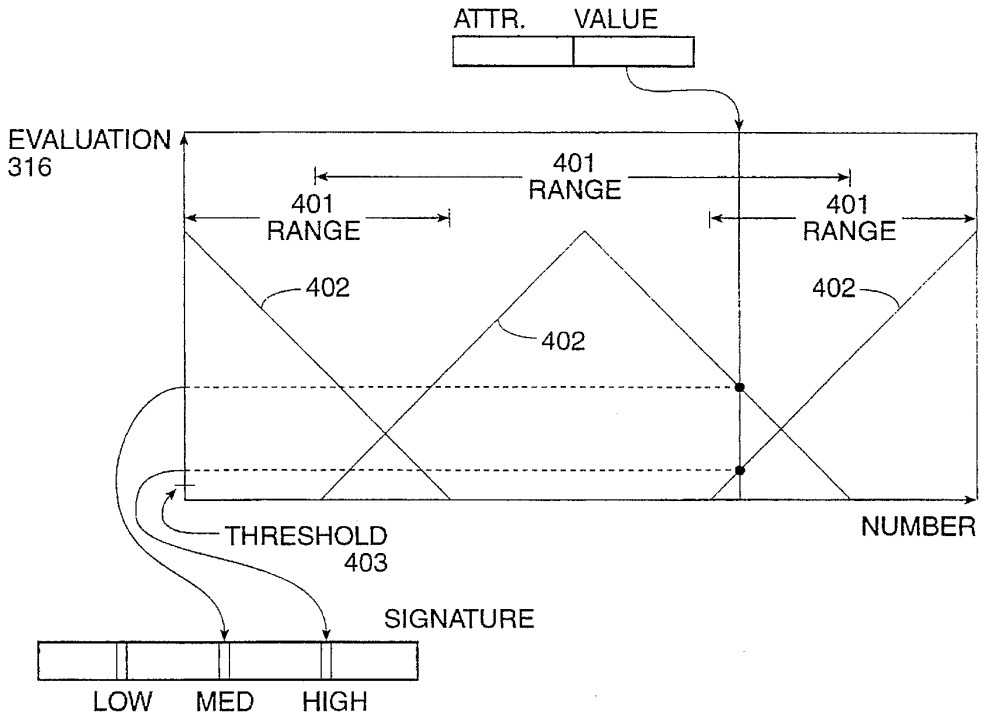

ATTR.
VALUE
EVALUATION
316
401
RANGE
401
RANGE
401
RANGE
402
402
402
THRESHOLD
403
NUMBER
SIGNATURE
LOW
MED
HIGH

FIG. 4A

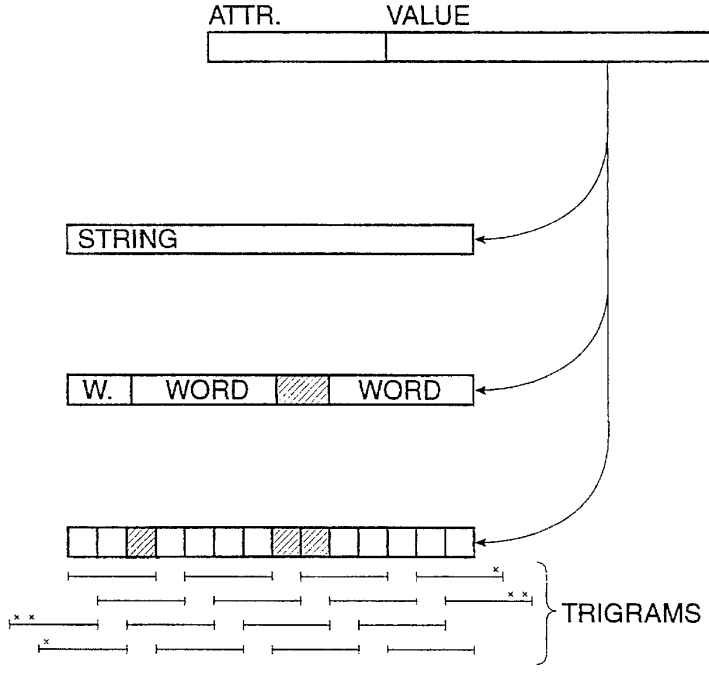
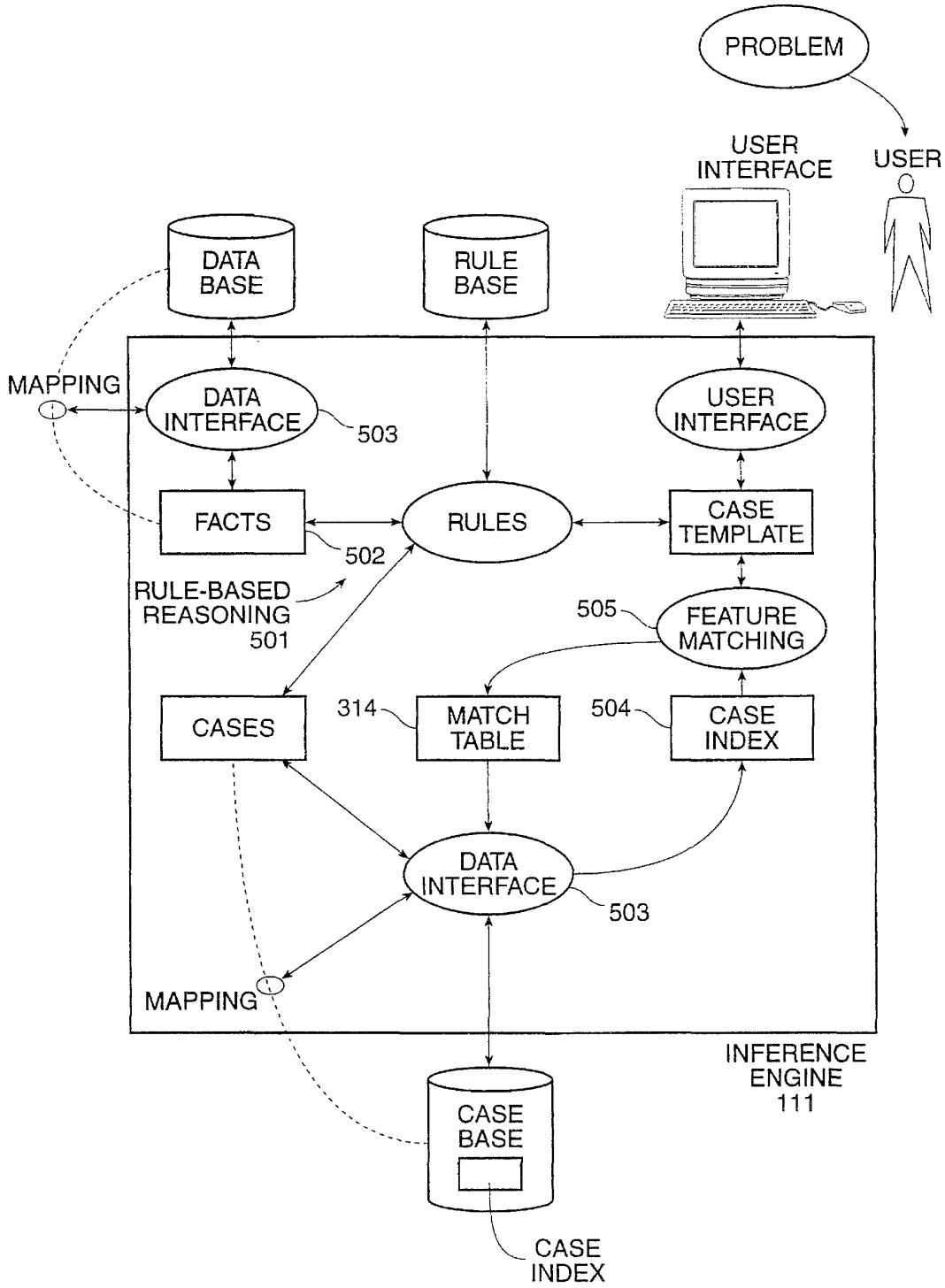

ATTR.
VALUE
STRING
W.
WORD
WORD
TRIGRAMS

FIG. 4B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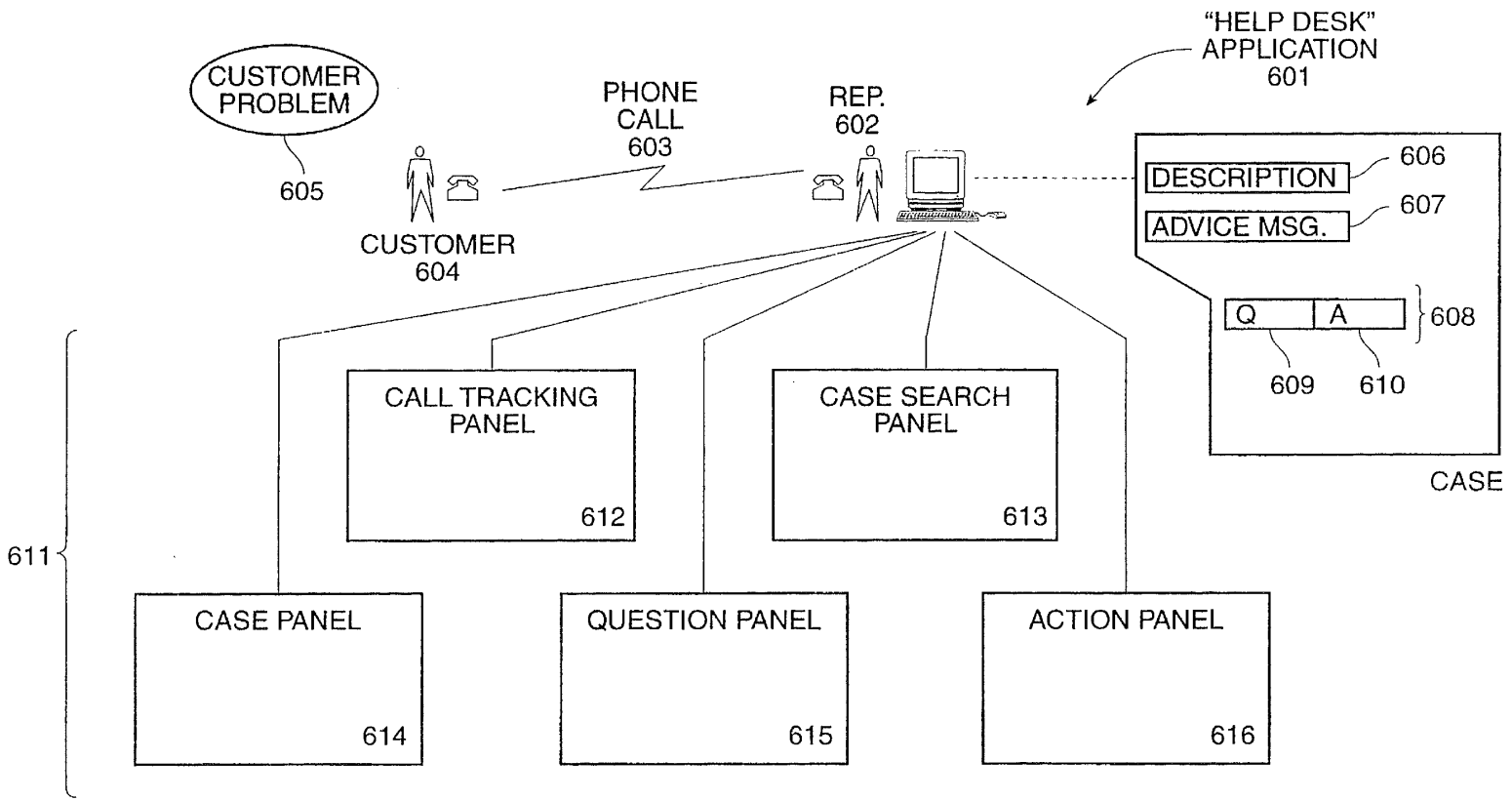
USER
DATA BASE
RULE BASE
MAPPING
DATA INTERFACE
503
USER INTERFACE
FACTS
502
RULES
CASE TEMPLATE
RULE-BASED REASONING 501
505
FEATURE MATCHING
CASES
314
MATCH TABLE
504
CASE INDEX
DATA INTERFACE
503
MAPPING
INFERENCE ENGINE 111
CASE BASE
CASE INDEX

FIG. 5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605
CUSTOMER 604
PHONE CALL 603
REP. 602
"HELP DESK" APPLICATION 601
DESCRIPTION
606
ADVICE MSG.
607
Q
A
608
609
610
CASE
611
CALL TRACKING PANEL
612
CASE SEARCH PANEL
613
CASE PANEL
614
QUESTION PANEL
615
ACTION PANEL
616

FIG. 6

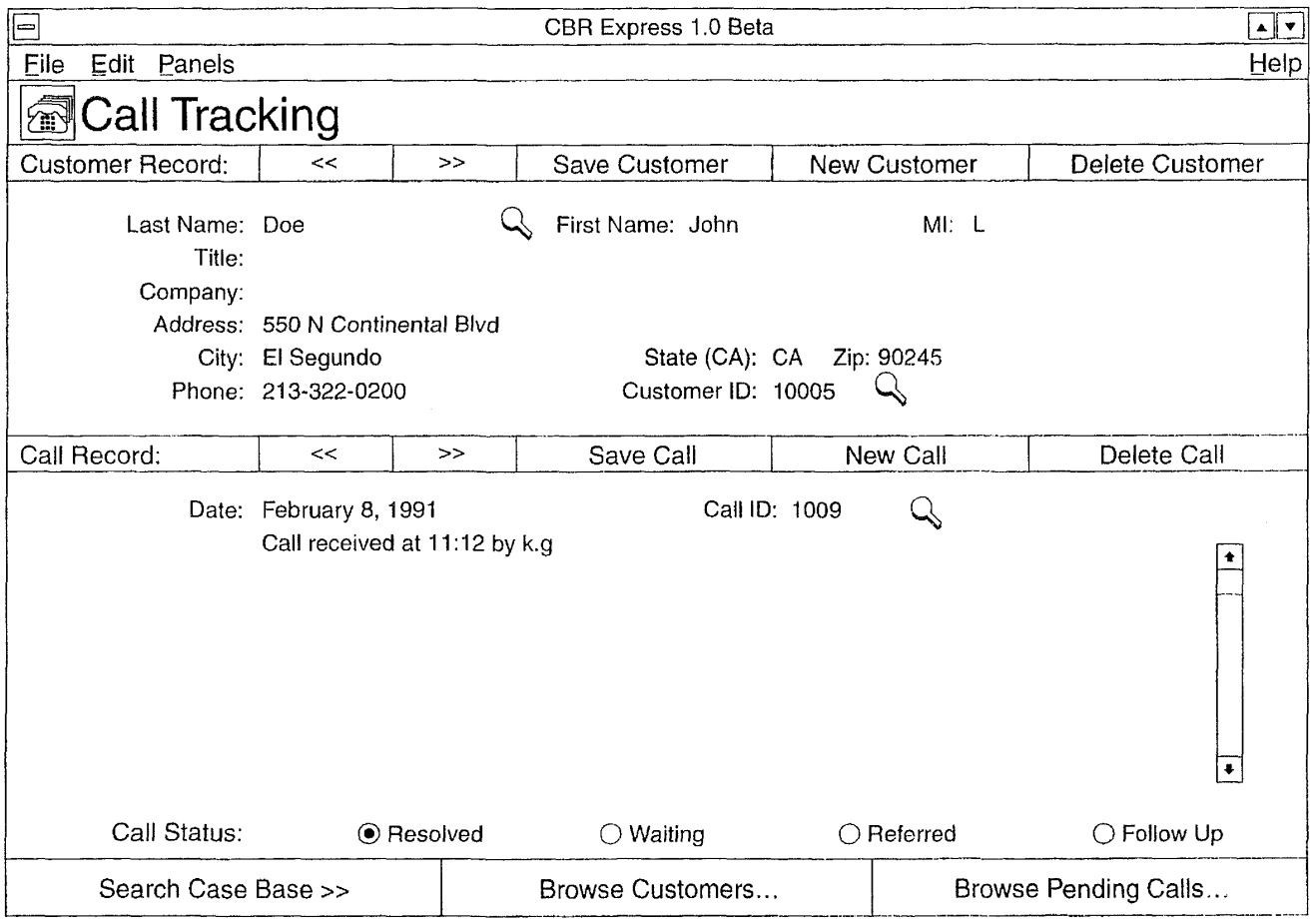
CBR Express 1.0 Beta
File Edit Panels
Help
Call Tracking
Customer Record:
<<
>>
Save Customer
New Customer
Delete Customer
Last Name: Doe
First Name: John
MI: L
Title:
Company:
Address: 550 N Continental Blvd
City: El Segundo
State (CA): CA
Zip: 90245
Phone: 213-322-0200
Customer ID: 10005
Call Record:
<<
>>
Save Call
New Call
Delete Call
Date: February 8, 1991
Call ID: 1009
Call received at 11:12 by k.g
Call Status:
Resolved
Waiting
Referred
Follow Up
Search Case Base >>
Browse Customers...
Browse Pending Calls...

FIG. 6A

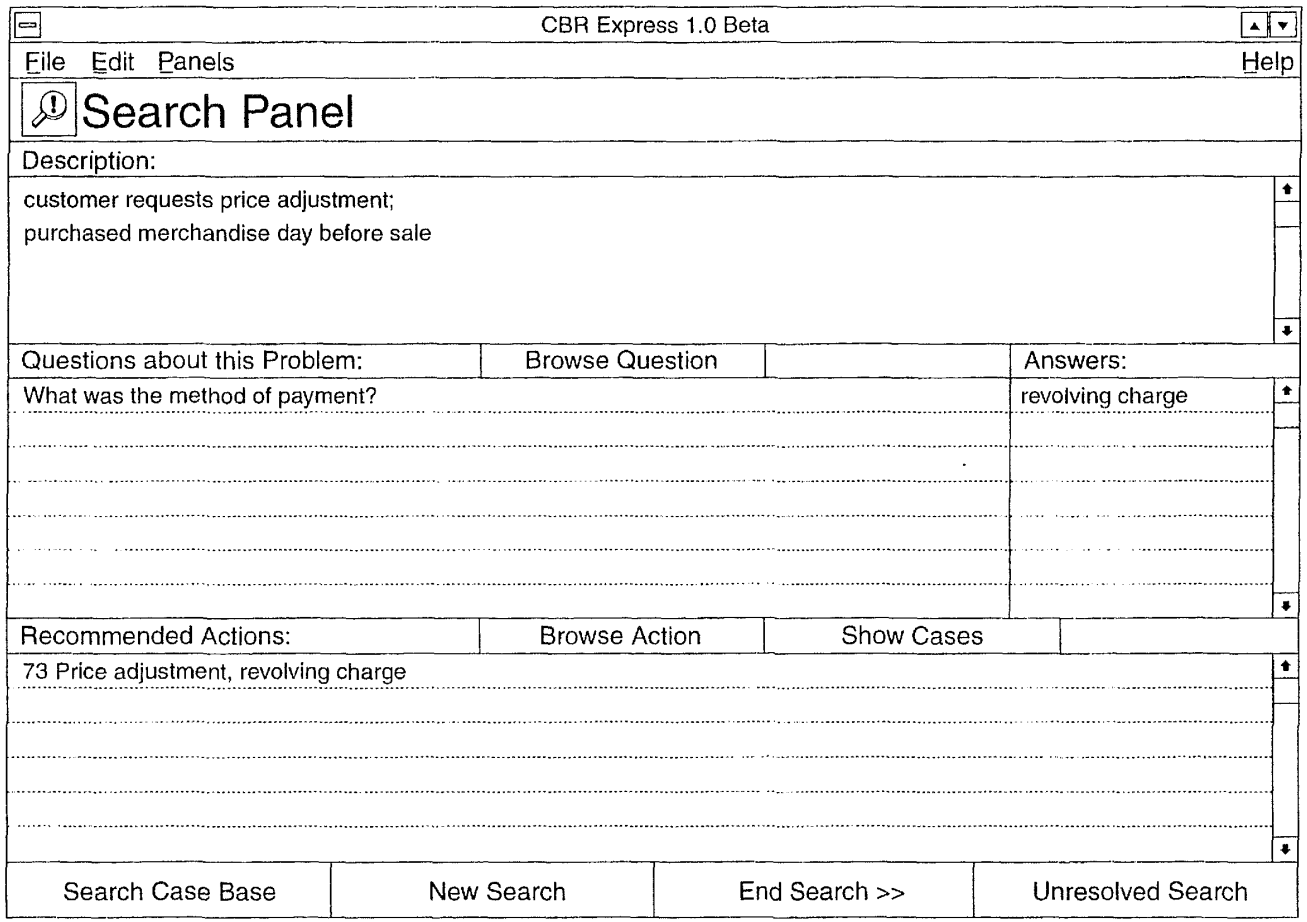
CBR Express 1.0 Beta
File Edit Panels
Help
Search Panel
Description:
customer requests price adjustment;
purchased merchandise day before sale
Questions about this Problem:
Browse Question
Answers:
What was the method of payment?
revolving charge
Recommended Actions:
Browse Action
Show Cases
73 Price adjustment, revolving charge
Search Case Base
New Search
End Search >>
Unresolved Search

FIG. 6B

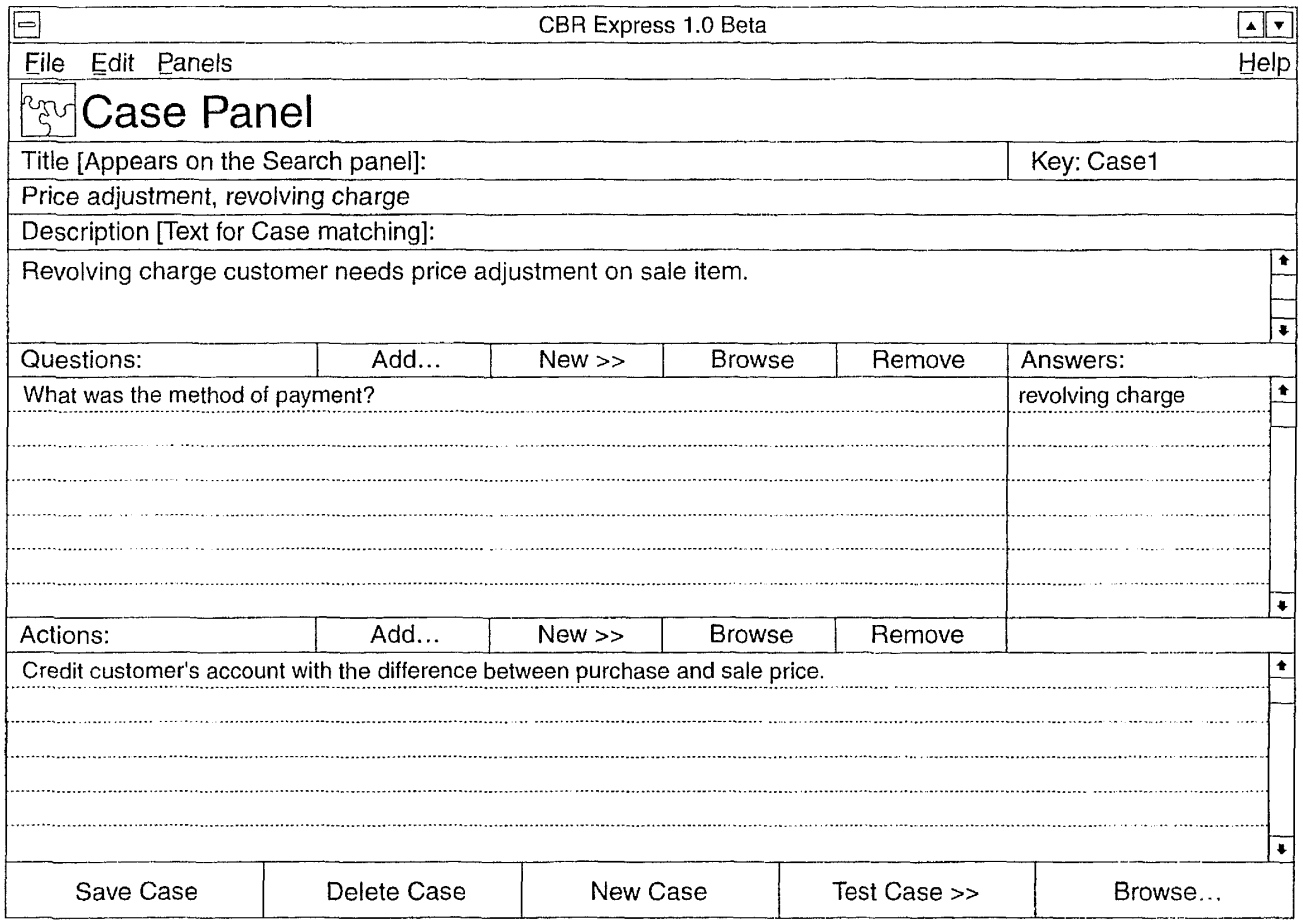
CBR Express 1.0 Beta
File Edit Panels
Help
Case Panel
Title [Appears on the Search panel]:
Key: Case1
Price adjustment, revolving charge
Description [Text for Case matching]:
Revolving charge customer needs price adjustment on sale item.
Questions:
Add...
New >>
Browse
Remove
Answers:
What was the method of payment?
revolving charge
Actions:
Add...
New >>
Browse
Remove
Credit customer's account with the difference between purchase and sale price.
Save Case
Delete Case
New Case
Test Case >>
Browse...

FIG. 6C

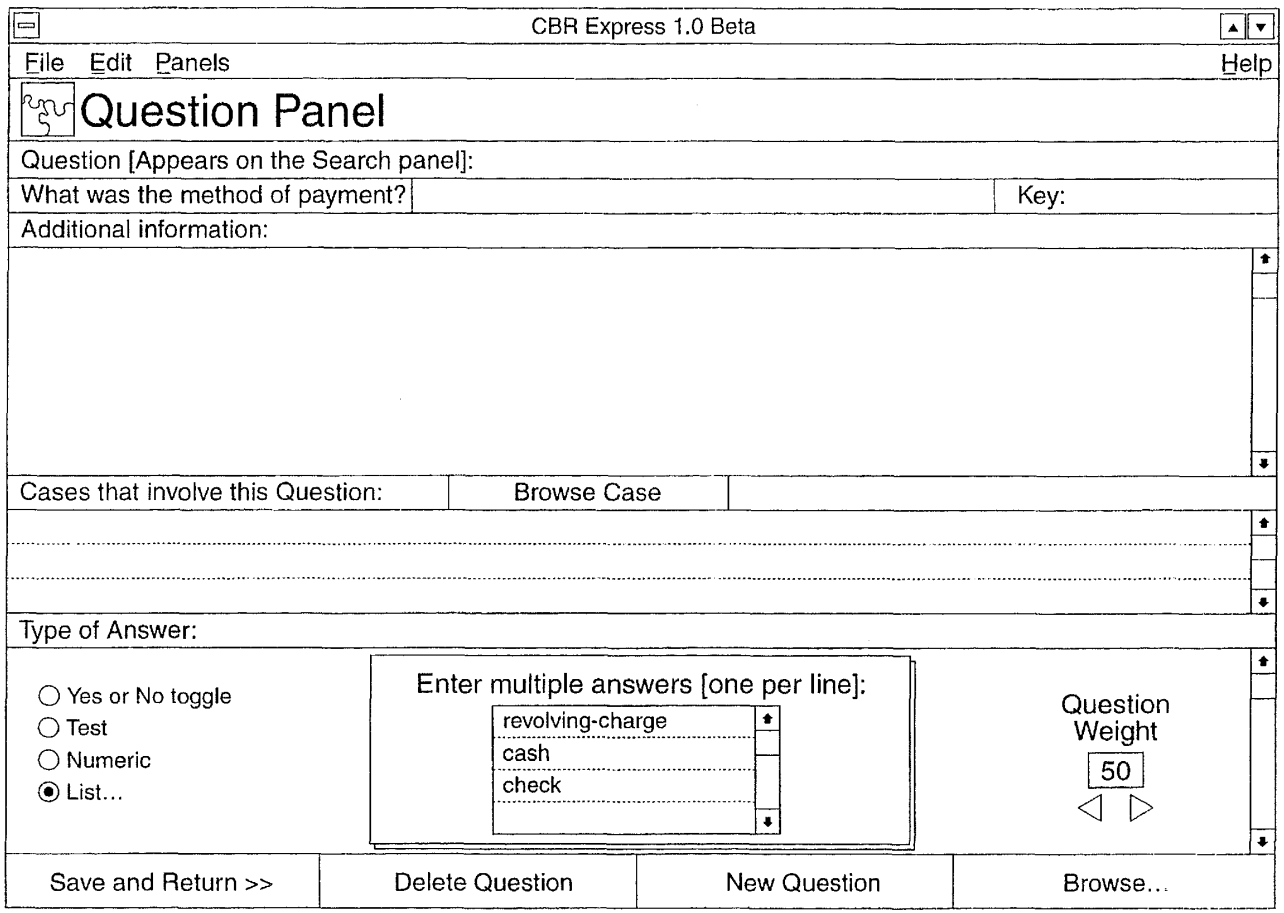
CBR Express 1.0 Beta
File Edit Panels
Help
Question Panel
Question [Appears on the Search panel]:
What was the method of payment?
Key:
Additional information:
Cases that involve this Question:
Browse Case
Type of Answer:
Yes or No toggle
Test
Numeric
List...
Enter multiple answers [one per line]:
revolving-charge
cash
check
Question Weight
50
Save and Return >>
Delete Question
New Question
Browse...

FIG. 6D

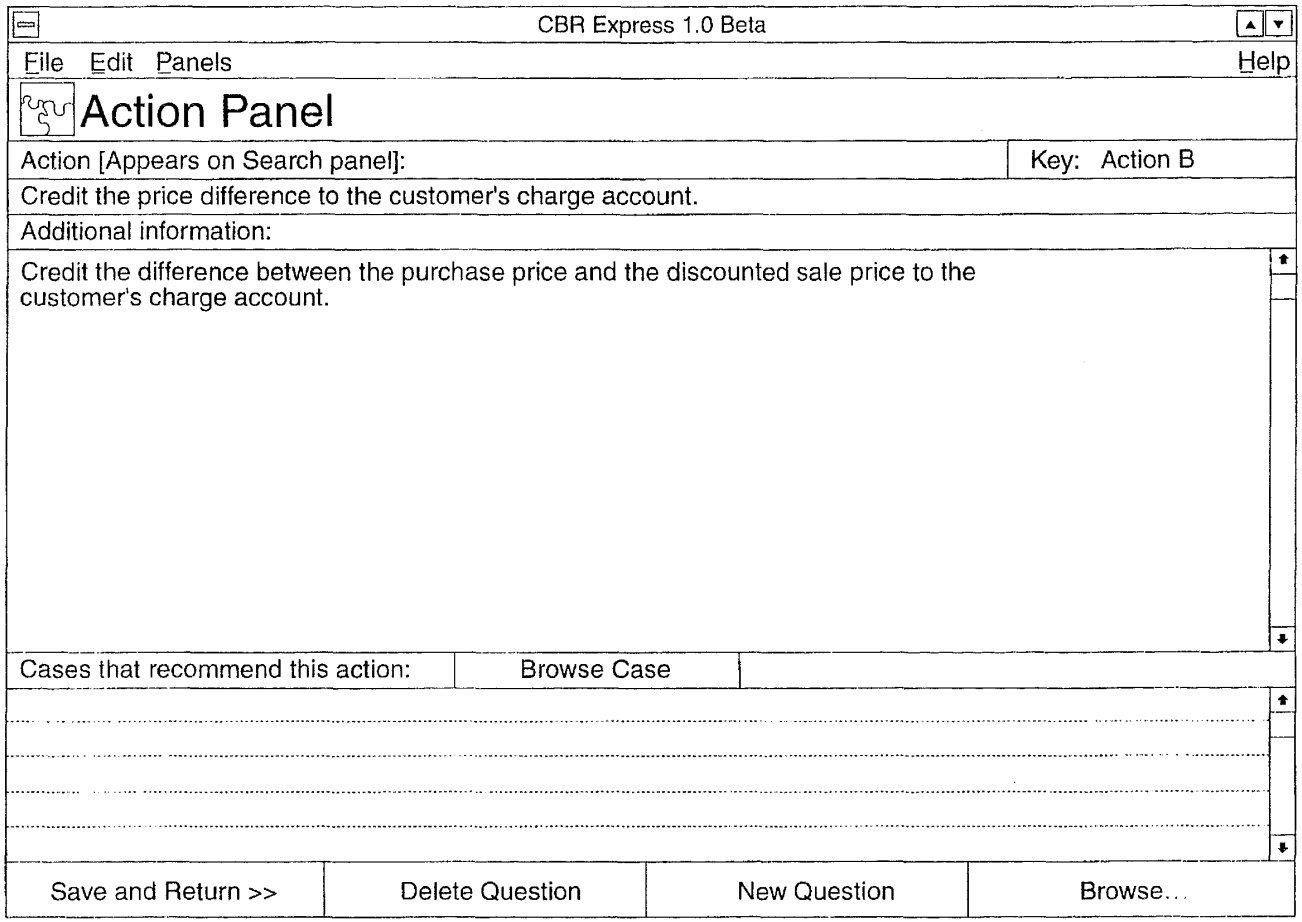
CBR Express 1.0 Beta
File Edit Panels
Help
Action Panel
Action [Appears on Search panel]:
Key: Action B
Credit the price difference to the customer's charge account.
Additional information:
Credit the difference between the purchase price and the discounted sale price to the customer's charge account.
Cases that recommend this action:
Browse Case
Save and Return >>
Delete Question
New Question
Browse...

FIG. 6E

CASE-BASED REASONING SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION

This is a file-wrapper continuation of patent application Ser. No. 07/664,561, filed Mar. 4, 1991, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to case-based reasoning and to a case-based reasoning component of a rule-based reasoning system.

2. Description of Related Art

While computers are capable of tremendous processing power, their ability to use that processing power for reasoning about complex problems has so far been limited. Generally, before a computer can be used to address a complex problem, such as one which requires the attention of a human expert, it has been necessary to distill the knowledge of that expert into a set of inferential rules (a "rule base") which allow an automated processor to reason in a limited field of application. While this method has been effective in some cases, it has the natural drawback that it often requires a substantial amount of time and effort, by both computer software engineers and experts in the particular field of application, to produce a useful product.

Moreover, rule-based systems of this type present a difficult programming task. Unlike more prosaic programming tasks, constructing a rule base is sometimes counter-intuitive, and may be beyond the ability of many application programmers. And once a rule-based system has been constructed based on the knowledge of a human expert, it may be difficult to accommodate Changes in the field of operation in which the processor must operate. Such changes might comprise advances in knowledge about the application field, additional tasks which are intended for the processor, or changes in or discoveries about the scope of the application field.

One proposed method of the prior art is to build automated reasoning systems which operate by reference to a set of exemplar cases (a "case base"), to which the facts of a particular situation (the "problem") may be matched. The processor may then perform the same action for the problem as in the exemplar case. While this proposal has been well-received, there have been several obstacles to successful implementation of a case-based reasoning system. One obstacle has been the lack of a feature matching technique which would be successful when applied to a case base of reasonable size. Another obstacle is that case-based reasoning can be relatively inflexible when the case base is insufficiently rich.

SUMMARY OF THE INVENTION

The invention provides a case-based reasoning system which is smoothly integrated into a rule-based reasoning system, thus coordinating case-based reasoning techniques and rule-based reasoning techniques in a unified automated reasoning system. In addition to matching a problem template to a case base, an automated processor may proceed by inferential reasoning on the facts of the problem and the cases by means of rule-based reasoning techniques (or based on procedural directives supplied by a human programmer). Thus, the processor may select the case which is the best match for the problem, but may act differently from the precise action prescribed for that case.

The invention also provides for dynamically adapting the case base to the problems which the automated reasoning system encounters. In addition to matching the problem to the "best" case, in addition to reasoning on the facts of the case based on rule-based reasoning, the processor may create additional cases which may exemplify the problem or which may be useful for future problems, or it may remove cases from the case base which it determines from experience are poor or obsolete. An aspect of the invention also includes a technique in which the processor may be set to work with a limited case base, and may solicit human advice for treatment of new problems which are not already well-treated by the case base. Thus, the processor may "learn" how to the do its job on a dynamic basis.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a block diagram of a unified automated reasoning system which incorporates a case-based reasoning system.

FIG. **2** shows a flow diagram for case-based reasoning.

FIG. **3**A shows a data flow diagram of a first feature-matching technique for matching a problem to one or more cases in a case base. FIG. **3**B shows a data flow diagram of a second such feature-matching technique.

FIG. **4**A shows a method for matching attribute-value pairs which have numeric values. FIG. **4**B shows a method for matching attribute-value pairs which have text string values.

FIG. **5** shows a block diagram of a case-based reasoning system implemented within a rule-based reasoning system.

FIG. **6** shows an example case-based reasoning system for providing user help on call-in complaints. FIGS. **6**A–**6**E show example display panels in detail.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. **1** shows a block diagram of a unified automated reasoning system which incorporates a case-based reasoning system.

A case-based reasoning system **101** for a particular application field may comprises a rule base **102** of inferential rules **103** suited to that field, a case base **104** of exemplar cases **105** which are notable in that field, and a data base **106** of relevant problem data **107** for that field. In a preferred embodiment, the data base **106** may comprise a set of data records **108** stored in a secondary memory **109**. For example, in a case-based reasoning system **101** for loan approval, the rule base **102** may comprise inferential rules **103** about the creditworthiness of the customer, the case base **104** may comprise exemplar cases **105** which are known to match common fact scenarios, and the data base **106** may comprise relevant problem data **107** such as loan payment histories, results of loan-officer interviews and credit-check data. In a preferred embodiment, the case base **104**, rule base **102**, and data base **106** may be stored in a computer memory.

An automated processor **110** may execute a software inference engine **111** for reasoning using the case base **104** and rule base **102**. In a preferred embodiment, the inference engine **111** may comprise a software environment having a set of manipulable software objects **112**, a set of software tools **113** for manipulating those software objects **112**, for maintaining a mapping **114** between the data records **108** of

the data base **106** and a set of representative objects **115** representing those data records **108**, and a software language **116** for defining software objects **112** and invoking tools **113**. The language **116** may also comprise software structures for defining and altering rules **103** (e.g., in the rule base **102**) and cases **105** (e.g., in the case base **104**) and, in a preferred embodiment, for defining and altering programming language procedural structures **117** such as software subroutines.

In a preferred embodiment, the inference engine **111** may execute a flow diagram for case-based reasoning like that disclosed with FIG. **2**. The inference engine **111** may also execute a flow diagram for rule-based reasoning like those which are well known in the art, including known aspects of rule-based reasoning such as attribute inheritance, hypothetical reasoning, and retraction. A more detailed description of a flow diagram which an inference engine **111** may follow for rule-based reasoning, and of rule-based reasoning systems, may be found in "ART-IM Reference Manual" available from Inference Corporation of El Segundo, Calif., and hereby incorporated by reference as if fully set forth herein.

In a preferred embodiment, the processor **110** may also comprise a user interface **118**, to interact with a human operator or user **119**. The user interface **118** may comprise an interactive terminal at which the user **119** may enter commands or data and at which the processor **110** may present information or questions to the user **119**. In a preferred embodiment, the user interface **118** may be used either for development of cases **105**, rules **103**, or procedural structures **117** for use in the application field, or for use by the end user **119** in the application field, but it may be preferred for some application fields to provide one user interface **118** for development and a different user interface **118** for use by the end user **119**.

In a preferred embodiment, the automated processor **110** may comprise a system having a processor, memory comprising a stored program, memory comprising data, and input/output devices, as is well known in the art. The operation and software structures of this system are described herein in terms of their functions and at a level of detail which would be clear to those of ordinary skill in the art. It would be clear to anyone of ordinary skill in the art, after perusal of the specification, drawings and claims herein, that modification and/or programming (using known programming techniques) of a processor of known design to achieve these functions would be a straightforward task and would not require undue experimentation.

In a preferred embodiment, the processor **110** may comprise an IBM-compatible PC configured to be able to execute the MicroSoft Windows 3.0 and DOS 3.1 software, and having a hard disk drive, a mouse, and a VGA display. At least a 286 processor with four megabytes of memory is preferred; a 386 processor with eight megabytes of memory is more preferred. The MicroSoft Windows 3.0 software is preferably executed in 386 enhanced mode.

FIG. **2** shows a flow diagram for case-based reasoning.

In a description step **201**, the inference engine **111** retrieves a description of the facts of a particular situation (the "problem"). In a preferred embodiment, the user **119** may enter data relating to the problem by means of the user interface **118**. For example, the user **119** may complete an on-screen form, or may answer a set of questions provided by data-gathering software in the inference engine **111**.

In a case-matching step **202**, the inference engine **111** attempts to match the problem to one or more cases **105** in the case base **104**. In a preferred embodiment, the inference engine **111** may use a feature-matching technique like that described with FIGS. **3**A and **3**B.

In a best-case step **203**, the inference engine **111** attempts to evaluate the cases **105** which were found in the case-matching step **202**, and determine a "best" case **204** to match the problem. In a preferred embodiment, the inference engine **111** may present a sequence of questions to the user **119** and retrieve answers from the user **119** about the problem and the cases **105** which were found.

In a note-action step **205**, the inference engine **111** determines the action prescribed by the "best" case **204**, and attempts to determine if that action is a correct action to perform. If so, the inference engine **111** proceeds to a do-action step **206**. Otherwise, the inference engine **111** proceeds to a new-case step **207**.

In the new-case step **207**, the inference engine **111** adds a new case **105** to the case base **104**. In a preferred embodiment, the inference engine **111** may retrieve information to enter into the case base **104** from the user **119** by means of the user interface **118**, including the correct action to perform. The inference engine **111** then proceeds to the do-action step **206**.

In the do-action step **206**, the inference engine **111** performs the action that was previously determined to be correct. For example, the inference engine **111** may present the user **119** with a suggested solution to the problem.

FIG. **3**A shows a data flow diagram of a first feature-matching technique for matching a problem to one or more cases **105** in the case base **104**.

Each case **105** may be manipulated as a software object **112** in the inference engine **111** software environment. Each case **105** may comprise a set of attributes **301**, each of which has a value **302**. Attributes **301** and values **302** are typically manipulated as an attribute-value pair **303**. In a preferred embodiment, attributes **301** may be particular to the application field, and values **302** may have data types which vary from one attribute **301** to another. For example, in a case-based reasoning system **101** for loan approval, each case **105** might have an attribute **301** such as "loan amount" which would have a numeric value **302**, an attribute **301** such as "approved" which would have a boolean value **302**, and an attribute **301** such as "payment history" which would have a value **302** which is a list or array structure.

In a preferred embodiment, data types for attributes **301** may comprise (a) a yes/no data type, i.e., a one-bit boolean value, (b) a numeric data type, (c) a text string data type, and (d) a multiple-choice data type, i.e., a data type in which the value **302** must be selected from a predetermined set of possible values **302**.

Each case **105** may have one or more signature functions **304** applied to each of its attribute-value pairs **303**. Each signature function **304** may generate one or more signature bits **305** in a bit-string signature **306** for the case **105**. In a preferred embodiment, two signature functions **304** each generate one signature bit **305** apiece, and the resultant signature bits **305** are logical-OR-ed together to generate the signature **306**.

The signatures **306** for all cases **105** may be combined in one or more signature files **307**, each of which maps a set of signatures **306** to a set of keys **308**. The keys **308** may be used to reference the cases **105** as manipulable software objects **112**, with all of their attribute-value pairs **303**, an action **309** prescribed for each case **105**, and a supplemental structure **310** of software objects **112** which may be kept by the inference engine **111** with each case **105**. In a preferred

embodiment, one signature file **307** may be maintained for each case base **104**.

To match a problem **311** to the cases **105** in the case base **104**, a case template **312** may be constructed for the problem **311** with attribute-value pairs **303** which correspond to notable parameters of the problem **311**. The signature functions **304** may be applied to the attributes **301** (and their values **302**) of the case template **312**. Each attribute-value pair **303** for the case template **312** may therefore generate a set of test bits **313** to be matched against the signatures **306** in the signature file **307**. In a preferred embodiment, each signature **306** in the signature file **307** may be logical-AND-ed together with the test bits **313**, and may generate a hit whenever a signature **306** in the signature file **307** has all the test bits **313** for a particular attribute-value pair **303** set to logical "1".

Cases **105** which are hits may be noted in a match table **314**. The cases **105** in the match table **314** may be evaluated for a match quality **315**, and the match quality **315** for each case **105** may be recorded in the match table **314**. In a preferred embodiment, the inference engine **111** may determine match quality **315** for each case **105** in the match table **314** by a weighted sum of an evaluation **316** of those attribute-value pairs **303** which are matched. In a preferred embodiment, the weights assigned to each attribute-value pair **303** may be predetermined and may be altered by the user **119**. The evaluation **316** of matched attribute-value pairs **303** may be like that disclosed with FIG. **4**A or **4**B.

In a preferred embodiment, cases **105** which are hits may have their match quality **315** compared against a quality threshold **317**, and those cases **105** which best meet the quality threshold **317** may be stored in the match table **314**, up to the size of the match table **314**. In a preferred embodiment, the quality threshold **317** and the size of the match table **314** may be predetermined and may be altered by the user **119**.

FIG. **3**B shows a data flow diagram of a second feature-matching technique for matching a problem to one or more cases **105** in the case base **104**. This feature-matching technique is presently preferred over the technique disclosed with FIG. **3**A.

Each case **105** may have one or more hash functions **318** applied to each of its attribute-value pairs **303**. Each hash function **318** may generate one or more locations **319** in a hash table **320** of attribute-value pairs **303**. Each location **319** may comprise a set of pointers **321** to one or more cases **105** in the case base **104**.

To match the case template **312** to the cases **105** in the case base **104**, the hash functions **318** may be applied to a set of attributes **301** (and their values **302**) of the case template **312**. Each attribute-value pair **303** for the case template **312** may therefore generate a set of locations **319** in the hash table **320**, and thus generate a set of pointers **321** to cases **105** in the case base **104**. In a preferred embodiment, the inference engine **111** may examine the locations **319** in the hash table **320** to examine attribute-value pairs **303** further, e.g. to determine if there is a match or if the hash functions **318** generated the same location **319** by coincidence.

In a preferred embodiment, cases **105** which are hit in this manner may be noted in the match table **314** and may have their match quality **315** determined, in like manner as disclosed with FIG. **3**A. Attributes **301** with numeric values **302** or with text string values **302** may be treated in like manner as disclosed with FIG. **4**A or **4**B.

FIG. **4**A shows a method for matching attribute-value pairs **303** which have numeric values **302**.

In a preferred embodiment, attributes **301** with a numeric data type may match based on a set of one or more numeric ranges **401**, such as a LOW range **401**, a MEDIUM range **401** and a HIGH range **401**. The inference engine **111** may compare the value **302** for the attribute **301** against the ranges **401** which are set for that attribute **301**, and apply an evaluation function **402** to generate the evaluation **316** of how well each value **302** matches each range **401**. The evaluation **316** may be compared against an evaluation threshold **403**, and matching for that attribute-value pair **303** may proceed on the basis that the value **302** falls within the range **401**. In a preferred embodiment, the evaluation function **402**, the evaluation threshold **403** and the ranges **401** may be predetermined and may be altered by the user **119**.

For example, for one attribute **301** the evaluation function **402** may treat values **302** of about zero as LOW, about 30 as MEDIUM and about 60 as HIGH. If the value **302** for that attribute **301** is 36, the attribute-value pair **303** will match the HIGH range **401** with the evaluation **316** of 0.2, will match the MEDIUM range **401** with the evaluation **316** of 0.8, and will not match the LOW range **401**.

FIG. **4**B shows a method for matching attribute-value pairs **303** which have text string values **302**.

In a preferred embodiment, an attribute **301** with a text string value **302** may be matched by string matching, word matching and character matching.

In string matching, the entire text string value **302** is matched exactly.

In word matching, the text string value **302** is broken up into separate words, by reference to word delimiter characters, as is well known in the art. A predetermined set of noise words, such as "a", "and" and "the", may also be removed Synonyms for the non-noise words may also be used for matching, and may be determined either globally or for a particular attribute **301**. The non-noise words are each recorded as separate attribute-value pairs **303** which may be matched exactly. For example, the text string "BRADLEY P. ALLEN" would match the words "BRADLEY", "P" and "ALLEN", and if "BRAD" is a synonym for "BRADLEY", would also match "BRAD".

In character matching, the words of the text string value **302**, as determined for word matching, are broken up into separate trigrams (substrings of length three). In a preferred embodiment, each word is prefixed and suffixed with two special initial/final characters prior to breaking each word into trigrams. The trigrams are each recorded as separate attribute-value pairs **303** which may be matched exactly. For example, the text string "DANIEL" would match the trigrams "xxD", "xDA", "DAN", "ANI", "NIE", "IEL", "ELx", and "Lxx", where "x" is the special initial/final character.

In a preferred embodiment, string matching, word matching and character matching are assigned weights, and the evaluation **316** of the text string match may be determined by a weighted sum of the evaluations **316** for each type of match. In a preferred embodiment, each word is assigned equal weight within word matching and each trigram is assigned equal weight within character matching.

The evaluation **316** of matched attribute-value pairs **303** may also be determined for other data types besides the numeric data type and the text string data type. In a preferred embodiment, the evaluation **316** may also be determined for matched attribute-value pairs **303** with a multiple-choice data type. For example, for a multiple-choice data type in which the choices are RED, ORANGE, YELLOW, GREEN, BLUE, and VIOLET, the evaluation **316** of matching

between RED and ORANGE might be 0.8, while the evaluation **316** of matching between RED and YELLOW might be 0.4, and the evaluation **316** of matching between RED and GREEN might be zero.

FIG. **5** shows a block diagram of a case-based reasoning system **101** implemented within a rule-based reasoning system.

In a preferred embodiment, the inference engine **111** for the case-based reasoning system **101** may be implemented within a rule-based reasoning system **501**, such as the ART-IM rule-based reasoning system, manufactured by Inference Corporation of El Segundo, Calif. In the rule-based reasoning system **501**, rules **103** may be matched against software objects **112**, including a set of facts **502**, cases **105** and the case template **312**, and may perform procedural actions on them. Software objects **112** may comprise data elements and relations to other software objects **112**, as is well known in the art. Object-oriented systems are more fully described in "Object-Oriented Design With Applications" by Grady Brooch, published by Benjamin/Cummings Publishing, Redwood City, Calif. (1991), hereby incorporated by reference as if fully set forth herein.

In a preferred embodiment, cases **105** may be implemented as software objects **112**, such as a "schema" in ART-IM. Each case **105** may comprise its attribute-value pairs **303** and its relations to other software objects **112**. For example, parameters of some problem **311** may be attributes **301** of some case **105**. Moreover, the prescribed action **309** for the case **105** may be the ACTION attribute **301** or some other attribute **301**. Its value **302** may be a text string describing the action **309**, or may be another type of software object **112** to which the inference engine **111** may apply rules **103** or procedural structures **117**.

The inference engine **111** may be coupled to the data base **106** by means of a data interface **503**. In a preferred embodiment, the data interface **503** may maintain the mapping **114** between the data records **108** of the data base **106** and the representative objects **115** representing those data records **108**. The data interface **503** may comprise procedural structures **117** for defining the format of the data records **108** in the secondary memory **109**, for allocating and deallocating memory in the processor **110** to record representative objects **115**, and for defining the format of the mapping **114** between the data records **108** and representative objects **115**.

For example, the data interface **503** may define data records **108** to comprise a sequence of bytes indicating a numeric data type, allocate memory in the processor **110** for a software object **112** with a numeric data type, and map the data records **108** to that software object **112**. With the data interface **503**, the inference engine **111** may operate on that software object **112** as if it were immediately available to the processor **110**, rather than in the secondary memory **109**.

A preferred data interface **503** is more fully described in "ART-IM Reference Manual" available from Inference Corporation of El Segundo, Calif., and hereby incorporated by reference as if fully set forth herein.

The inference engine **111** may also be coupled to the case base **104** by means of the data interface **503**. Cases **105** may be recorded in the secondary memory **109**, and may be mapped to the memory in the processor **110** so the inference engine **111** may manipulate them as software objects **112**. In a preferred embodiment, the data interface **503** may compile a case index **504** from the case base **104**, which may comprise one or more signature files **307** (as in FIG. **3**A) or hash tables **320** (as in FIG. **3**B). The case index **504** may also be partly or fully recorded in the secondary memory **109** with the case base **104**, and may be moved from one processor **110** to another, with or without the case base **104**.

The inference engine **111** may perform a flow diagram with the data interface **503** like that disclosed with FIG. **2**. Facts about the problem **311** may be gleaned from the user **119** by means of the user interface **118** and recorded in the case template **312**. The case template **312** may be matched against the case base **104** using the case index **504** with a feature-matching procedure **505** like that disclosed with FIG. **3**A or **3**B. Some number of cases **105** may be recorded in the match table **314** by the feature-matching procedure **505**, of which one may be the "best" case **204**. As the inference engine **111** is implemented within the rule-based reasoning system **501**, it may also apply rules **103** or procedural structures **117** to the case template **312** before matching, and to the matched cases **105** after matching.

In a preferred embodiment, the inference engine **111** may add new cases **105** to the case base **104** when it determines that they are needed. In the case-matching step **202** or in the best-case step **203**, the inference engine **111** may determine that there is no case **105** which is a good match for the case template **312**. The inference engine **111** may create a new case **105** which partly or fully copies the case template **312**, and may ask the user **119** (by means of the user interface **118**) what the prescribed action **309** for the case **105** should be. The inference engine **111** may add the new case **105** to the case base **104** and proceed to another problem **311** with an augmented case base **104**.

The inference engine **111** may also add new cases **105** to the case base **104** without asking the user **119**. When the inference engine **111** determines that there is no case **105** which is a good match for the case template **312**, it may invoke a rule **103** or a procedural structure **117** which creates a new case **105**, which may partly or fully copy the case template **312**. Since cases **105** are software objects **112**, a rule **103** may create a new case **105** and may assign a value **302** to the ACTION attribute **301** (as well as to other attributes **301**).

In the note-action step **205**, the inference engine **111** may also determine that the case template **312** matches one or more cases **105** in the case base **104**, but that the actions **309** prescribed by those cases **105** are incorrect. For example, the inference engine **111** may invoke rules **103** which check that the action **309** for the "best" case **204** is inconsistent with known facts **502**, or the inference engine **111** may maintain a subsequent history with the case **105** and invoke rules **103** which determine if the action **309** taken was successful, or the inference engine **111** may ask the user **119** at a later time if the action **309** taken was successful.

The inference engine **111** may also remove cases **105** from the case base **104** when it determines that those cases **105** are poor or obsolete. In the note-action step **205**, should the inference engine **111** determine that the action **309** for the "best" case **204** is incorrect (e.g., by techniques noted herein) it may determine that the case **105** is no longer a good exemplar case **105** and may remove it from the case base **104**. The inference engine **111** may proceed to the next problem **311** with a corrected case base **104**.

FIG. **6** shows an example case-based reasoning system **101** for providing user help on call-in complaints.

One application field for case-based reasoning systems **101** may comprise an automated "help desk" application **601** for assisting a company's customer service personnel in giving advice to customers who call in with problems or

questions. Automated help desk systems typically comprise a telephone call management system, a problem tracking database, and on-line documentation. Using case-based reasoning to identify similar problems and record advice for such problems would provide for a quicker and more reliable automated help desk system.

In the automated help desk application **601**, the user **119** may comprise a customer service representative **602**, who may typically be receiving a telephone call **603** from a customer **604**. A set of customer problems **605** and advice to respond with may be stored as cases **105**. Attributes **301** of the cases **105** may include features of the customer problems **605**. In addition to matching on the description **606**, the application **601** may ask questions and obtain answers which allow it to determine which case **105** is the "best" case **204**, and thus to provide appropriate advice.

The automated "help desk" application **601** may perform a flow diagram like that disclosed with FIG. **2**, with some modifications. In the description step **201**, the application **601** may retrieve a text string description **606** of the customer problem **605**. In the case-matching step **202**, the application **601** may attempt to match the customer problem **605** to one or more cases **105** in the case base **104** using just the description **606** of the customer problem **605**. If the match quality **315** of the case **105** which are matched is high, the application **601** may perform the best-case step **203** and following steps. The action **309** which the application **601** performs is to provide an advice message **607** to the customer service representative **602**, who may then provide advice to the customer **604**.

However, it may occur that cases **105** which are matched all have low match quality **315**. The application **601** may collect a set of question-answer pairs **608** from the cases **105** which are matched. The application **601** may present a set of questions **609** from the question-answer pairs **608** to the customer service representative **602**, who would provide a set of answers **610** to the application **601** (typically by asking the customer **604**). The application **601** may perform the case-matching step **202** with the question-answer pairs **608** as additional attribute-value pairs **303** to match. In a preferred embodiment, weights may be assigned to the description **606** and to each question-answer pair **608**.

If no "best" case **204** can be matched even with the question-answer pairs **608**, the application **601** may create a new case **105** which copies the case template **312** and ask the customer service representative **602** for the advice message **607** to include with the case **105**. In a preferred embodiment, the application **601** may be operated with few cases **105** or even no cases **105** to start with, since the application **601** may create new cases **105** when there is no "best" case **204** in the case base **104**.

In a preferred embodiment, the application **601** may communicate with the user **119** by means of a set of display panels **611**. Each panel **611** may comprise a display window which may present information to, and/or request information from, the user **119**, typically with a form to be completed. Each panel **611** may comprise data fields which the user **119** may read or write, plus command icons which the user **119** may indicate (with a pointing device such as a mouse) to tell the application **601** to perform those commands. In a preferred embodiment, the application **601** may present the panel **611** which is appropriate to the case-based reasoning step it is performing, or the user **119** may direct the application **601** to display particular panels **611**.

In a preferred embodiment, the panels **611** may also present and/or request graphical information, such as an electronic circuit diagram or an exploded view of an automobile. The panels **611** may also present information in hypertext format, as is well known in the art. Thus, the user **119** may request more information about a particular segment of text by identifying that segment (e.g., with a pointing device such as a mouse) and requesting that the application **601** display more information.

A call tracking panel **612** may present and/or request information relating to customers **604** who call and the telephone calls **603** they have made to the customer service representative **602**. Thus, the user **119** may identify new customers **604** and new telephone calls **603** using the call tracking panel **612**. FIG. **6**A shows the call tracking panel **612** in detail.

A case search panel **613** may present and/or request information relating to the customer problem **605**. Thus, the user **119** may define the case template **312** using the case search panel **613**. The customer service representative **602** may also answer questions by means of the case search panel **613**. FIG. **6**B shows the case search panel **613** in detail.

A case panel **614** may present and/or request information relating to new cases **105**. Thus, the user **119** may define new cases **105** using the case panel **614**. The case panel **614** may typically be used by users **119** who are experts on the company's product, and the customer service representative **602** may not need to use the case panel **614** at all. FIG. **6**C shows the case panel **614** in detail.

A question panel **615** may present and/or request information relating to question-answer pairs **608**. Thus, the user **119** may create new questions **609** and record possible answers **610** for cases **105**, using the question panel **615**. The question panel **615** may typically be used by users **119** who are experts on the company's product, and the customer service representative **602** may not need to use the question panel **615** at all. FIG. **6**D shows the question panel **615** in detail.

An action panel **616** may present and/or request information relating to actions **309**. Thus, the user **119** may create new actions **309** or alter old actions **309** using the action panel **616**. The action panel **616** may typically be used by users **119** who are experts on the company's product, and the customer service representative **602** may not need to use the action panel **616** at all. FIG. **6**E shows the action panel **616** in detail.

A preferred example case-based reasoning system **101** for providing user help on call-in complaints is more fully described in "CBR Express User's Guide", available from Inference Corporation of El Segundo, Calif., and hereby incorporated by reference as if fully set forth herein.

Alternative Embodiments

While preferred embodiments are disclosed herein, many variations are possible which remain within the concept and scope of the invention, and these variations would become clear to one of ordinary skill in the art after perusal of the specification, drawings and claims herein.

We claim:

1. A case-based reasoning system, comprising

a rule base having a plurality of inferential rules;

a case base having a plurality of exemplar cases;

a data base having a plurality of data records having a plurality of data items external to a set of facts in a problem template and external to a set of derived facts concluded from said set of facts; and

an inference engine comprising means for performing case-based reasoning steps on said cases and said problem template, and comprising means for performing rule-based reasoning steps on said data items external to said set of facts in said problem template and external to said derived facts using said rules in a unified automated reasoning system;

wherein said inference engine comprises means for matching said problem template having a set of facts to

said case base; and means for applying said rules to said cases, said data items in said data records external to said set of facts in said problem template and external to said derived facts, and said facts in said problem template;

wherein said inference engine comprises a set of software objects which correspond to said cases and said data items and wherein said system comprises a data interface comprising means for maintaining a mapping between said data items and a first set of representative software objects, and means for maintaining a mapping between said cases and a second set of representative software objects.

2. A system as in claim **1**, wherein said inference engine comprises means for selecting a case which is a best match for said problem template; and means for selecting an action which differs from an action prescribed for that case in response to said data items external to said facts said problem template and external to said derived facts.

3. A system as in claim **2**, wherein said means for selecting a case comprises means for retrieving a set of matching cases for said problem template, and said means for selecting an action comprises means for performing rule-based reasoning steps on said set of matching cases.

4. A system as in claim **1**, wherein said inference engine comprises means for adding a new case to said case base in response to a plurality of problem templates which said system encounters.

5. A system as in claim **4**, wherein said new case comprises at least one attribute-value pair which is copied from an unmatched problem template.

6. A system as in claim **4**, wherein said new case comprises at least one attribute-value pair which is input from a human operator.

7. A system as in claim **4**, wherein said inference engine comprises means for adding a new case to said case base, wherein said new case matches an unmatched problem template and wherein an action for said new case is externally input.

8. A system as in claim **1**, wherein said inference engine comprises means for removing an old case from said case base in response to a set of problems which said system encounters.

9. A system as in claim **1**, comprising a case base which has been constructed substantially by adding new cases in response to a set of unmatched problem templates.

10. A system as in claim **1**, comprising a case base which has been constructed substantially by adding new cases in response to external input.

11. A system as in claim **2**, comprising a case base which has been constructed substantially by adding new cases and removing old cases from a predetermined case base, in response to a set of problems which said system encounters.

12. A system as in claim **1**, wherein said inference engine comprises a data interface comprising means for maintaining a case index.

13. A system as in claim **1**, wherein said inference engine comprises a case index transported from a second case-based reasoning system.

14. A system as in claim **1**, wherein said inference engine comprises a data interface which comprises for maintaining a mapping between said software objects and said cases, and comprises means for maintaining a mapping between said software objects and said data items.

15. A system as in claim **1**, wherein said inference engine comprises means for constructing said problem template in response to a request for information from an external source.

16. A system as in claim **15**, wherein said means for constructing said problem template comprises means for soliciting information from a human operator.

17. A system as in claim **1**, wherein said inference engine comprises means for matching said problem template against said case base.

18. A system as in claim **17**, wherein said means for matching comprises a case index.

19. A case-based reasoning system, comprising

a rule base having a plurality of inferential rules;

a case base having a plurality of exemplar cases;

a data base having a plurality of data records having a plurality of data items external to a set of facts in a problem template and external to a set of derived facts concluded from said set of facts; and

an inference engine comprising means for performing case-based reasoning steps on said cases and said problem template, and comprising means for performing rule-based reasoning steps on said data items external to said set of facts in said problem template and external to said derived facts using said rules in a unified automated reasoning system;

wherein said inference engine comprises means for matching said problem template having a set of facts to said case base; and means for applying said rules to said cases, said data items in said data records external to said set of facts in said problem template and external to said derived facts, and said facts in said problem template;

wherein said inference engine comprises a data interface which is responsive to a match table of said cases.

20. A case-based reasoning system, comprising

a rule base having a plurality of inferential rules;

a case base having a plurality of exemplar cases;

a data base having a plurality of data records having a plurality of data items external to a set of facts in a problem template and external to a set of derived facts concluded from said set of facts; and

an inference engine comprising means for performing case-based reasoning steps on said cases and said problem template, and comprising means for performing rule-based reasoning steps on said data items external to said set of facts in said problem template and external to said derived facts using said rules in a unified automated reasoning system;

wherein said inference engine comprises means for matching said problem template having a set of facts to said case base; and means for applying said rules to said cases, said data items in said data records external to said set of facts in said problem template and external to said derived facts, and said facts in said problem template;

wherein said inference engine comprises means for constructing said problem template in response to a request for information from an external source;

wherein said means for constructing said problem template comprises means for engaging a human operator in a question-answer dialogue.

21. A case-based reasoning system, comprising

a rule base having a plurality of inferential rules;

a case base having a plurality of exemplar cases;

a data base having a plurality of data records having a plurality of data items external to a set of facts in a problem template and external to a set of derived facts concluded from said set of facts; and

an inference engine comprising means for performing case-based reasoning steps on said cases and said

problem template, and comprising means for performing rule-based reasoning steps on said data items external to said set of facts in said problem template and external to said derived facts using said rules in a unified automated reasoning system;

wherein said inference engine comprises means for matching said problem template having a set of facts to said case base; and means for applying said rules to said cases, said data items in said data records external to said set of facts in said problem template and external to said derived facts, and said facts in said problem template;

wherein said inference engine comprises means for matching said problem template against said case base;

wherein said means for matching comprises a match table.

22. A case-based reasoning system, comprising

a rule base having a plurality of inferential rules;

a case base having a plurality of exemplar cases;

a data base having a plurality of data records having a plurality of data items external to a set of facts in a problem template and external to a set of derived facts concluded from said set of facts;

an inference engine comprising means for performing case-based reasoning steps on said cases and said problem template, and comprising means for performing rule-based reasoning steps on said data items external to said set of facts in said problem template and external to said derived facts using said rules in a unified automated reasoning system;

wherein said inference engine comprises means for matching said problem template having a set of facts to said case base; and means for applying said rules to said cases, said data items in said data records external to said set of facts in said problem template and external to said derived facts, and said facts in said problem template; and

means for performing a method of matching a problem template to a case base, said method comprising the steps of

first generating a set of signature bits in response to at least one attribute-value pair for each case in said case base;

second generating a set of signatures, one for each said case, in response to said set of signature bits;

recording a signature file having at least one mapping from said set of signatures to said cases;

third generating a set of test bits for said problem template; and

searching said signature file in response to said test bits.

23. A system as in claim **22**, wherein said first generating step comprises applying at least one signature function to said at least one attribute-value pair.

24. A system as in claim **22**, wherein said third generating step comprises applying at least one signature function to at least one attribute-value pair for said problem template.

25. A system as in claim **22**, wherein said at least one attribute-value pair comprises an attribute with a data type selected from the group: numeric, boolean, list structure, array structure, text string, multiple-choice.

26. A system as in claim **22**, wherein said third generating step is responsive to at least one numeric range for an attribute-value pair with a numeric data type.

27. A system as in claim **22**, wherein said third generating step generates a first test bit in response to whether a value in said attribute-value pair falls within a first range and generates a second test bit in response to whether said value falls within a second range.

28. A system as in claim **22**, wherein said third generating step is responsive to string matching, word matching, or character matching, for an attribute-value pair with a text string data type.

29. A system as in claim **22**, wherein said third generating step generates a set of test bits in response to at least one substring of a value in an attribute-value pair with a text string data type.

30. A system as in claim **29**, wherein said at least one substring comprises a set of words found in a said value.

31. A system as in claim **29**, wherein said at least one substring comprises a set of trigrams found in said value.

32. A system as in claim **29**, wherein said at least one substring comprises at least one substring of said value after a predetermined set of characters has been removed from said value.

33. A system as in claim **22**, wherein a set of cases which are matched are recorded in a match table.

34. A system as in claim **22**, wherein a set of cases which are matched are evaluated for quality of match.

35. A system as in claim **22**, wherein said third generating step is responsive to a plurality of values in an attribute-value pair with a multiple-choice data type.

36. A case-based reasoning system, comprising

a rule base having a plurality of inferential rules;

a case base having a plurality of exemplar cases;

a data base having a plurality of data records having a plurality of data items external to a set of facts in a problem template and external to a set of derived facts concluded from said set of facts;

an inference engine comprising means for performing case-based reasoning steps on said cases and said problem template, and comprising means for performing rule-based reasoning steps on said data items external to said set of facts in said problem template and external to said derived facts using said rules in a unified automated reasoning system;

wherein said inference engine comprises means for matching said problem template having a set of facts to said case base; and means for applying said rules to said cases, said data items in said data records external to said set of facts in said problem template and external to said derived facts, and said facts in said problem template; and

means for performing a method of matching a problem template to a case base, said method comprising the steps of

first generating a case location in a hash table in response to at least one attribute-value pair for each case in said case base;

recording at least one pointer to a case in each one of said case locations;

second generating at least one problem locationin said hash table in response to at least one problem attribute-value pair; and

selecting among a set of cases pointed to by said pointers found in said hash table at said at least one problem location.

37. A system as in claim **36**, wherein said first generating step comprises applying a hash function to said at least one attribute-value pair.

38. A system as in claim **36**, wherein said second generating step comprises applying a hash function to said at least one problem attribute-value pair.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,581,664
DATED : December 3, 1996
INVENTOR(S) : Bradley P. Allen, S. Daniel Lee

It is certified that error appears in the above-indentified patent and that said Letters Patent is hereby corrected as shown below:

On title page item [56], other publications lines 1 & 5, page 2, col. 1, line 10, delete "Workship" insert--Workshop--
page 2, col. 1, line 54, delete "Sofware" insert --Software--;
page 2, col. 2, line 2, delete "Retrieival" insert --Retrieval--;
page 2, col. 2, line 40, delete "Knowledged" insert --Knowledge--;
page 2, col. 2, line 59, delete "Intellignece" insert --Intelligence--;
page 3, col. 2, line 8, delete "Adressable" insert--Addressable--; and
page 3, col.2, line 14, start "U.S. Naval ..." on newline.
Col. 1, line 36, replace "Changes" with --changes--.
Col. 2, line 46, after "field" delete "may".
Col. 6, line 32, after "removed" insert --.--.
Col. 11, line 18, after "facts" insert --in--.
Col. 11, line 57, after comprises insert --means--.
Col. 14, line 55, replace "locationin" with --location in--.
Col. 9, line 25, replace "case" with --cases--.

Signed and Sealed this
Eighth Day of April, 1997

Attest:

BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks