A Tool for Provider Interaction During Patient Care: G-CARE

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We have extended the CARE language to facilitate interaction with providers using the Medical Gopher order entry system during patient care to create G-CARE. We have used G-CARE in several randomized controlled trials and for routine clinical applications. The language has evolved and is now able to support nearly all of the decision support. Its flexibility allows G-CARE results to be used at many points throughout the patient care process. Based on actual use of G-CARE, we have found performance issues and lack of dynamically grouped order sets are limitations which need to be addressed.

INTRODUCTION

The Regenstrief Medical Record System (RMRS) is one of the oldest electronic patient record systems[1,2,3,4]. The CARE language has been used for decision support for over 20 years[5]. McDonald and his colleagues have repeatedly demonstrated the value of reminders generated using CARE[6,7,8,9].

We began to develop a physician workstation, the Medical Gopher*, in 1982. The CARE language was re-designed in order to interact with the provider in real time, as they are caring for the patient in that environment in 1992. We call the revised version G-CARE.

There are a variety of points in the patient care process at which feedback to the physician may alter behavior. Inappropriately placed or timed feedback will decrease compliance[10]. Once you move beyond the basic reflex order in which simple state variables trigger a single reminder (e.g. high serum potassium and patient receiving a potassium containing drug trigger a suggestion to discontinue the drug) most tools and syntax become limiting.

This paper will describe G-CARE with an emphasis on the tools needed to support complex interaction with the clinician during patient care.

METHODS

Physician Workstation

The Medical Gopher is a personal computer based system which provides an integrated environment in which providers can review patient information, clinical reference material, administrative data, communicate with other members of the care team, generate reports and write orders[11]. The Gopher is used now by physicians for all inpatient services to write orders at Wishard Memorial Hospital and for all outpatient care in the primary care General Medicine Practice at the Regenstrief Health Center[12].

Clinical data is stored in the Regenstrief Medical Record System (RMRS) VAX and downloaded to a Novell based file server when a patient begins an encounter. These data are loaded directly onto the provider's workstation whenever the provider initiates an order or review session on a particular patient.

G-CARE rule types

G-CARE rules are a declarative form of CARE, a procedural language developed for performing queries and alerts in the RMRS. Each rule produces a multivalued result which may include a date, parameter identifier, numeric value, logical value, messages, orders and comments. The interpretation of each of these components is context dependent. The numeric result for a drug can be the average daily dose while the numeric result for a diagnosis is empty. Six types of rules are defined. Different data are required to implement each rule type (Table 1).

Common characteristics

All rules can have an exclusion criteria. If the

* Not related to the Internet Gopher

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exclusion criteria is true, then the rule is immediately declared false. The exclusion criteria typically consists of a logical combination of other G-CARE rules.

Rules retain their truth states and carry values for a user specified "life time" or duration. Rules are not re-evaluated until this time limit is exceeded. A duration is required for all types of rules. If the life time is zero, for example, the rule will be recalculated whenever another rule encounters the rule in question. If the life time is 1 day, the rule will be recalculated if it was last evaluated more than 24 hours ago. The life time was implemented for computational efficiency. Data which changes on a slower time scale such as problem lists might have a life time of 1 day while those for laboratory results might have a life time of zero.

Table 1- G-CARE Rule Types

Rule Type	Description
Algebraic	Creates a numeric result by evaluating an expression
Logical	Creates a logical result of True or False by evaluating an expression
Prompt	Creates a simple form to request data from the user
Reminder	Returns one of a set of possible reminder text and/or suggested order set with comments pairs based on evaluation of conditions
Selection	Retrieves data from other CARE rules or the Gopher MRF
Special	Executes R-BASIC code

G-CARE rules may be of six types.

Selection rules

Selection rules retrieve data from the patient's electronic medical record. Such rules can return the first, last, maximum, minimum, or arithmetic mean of observations in the database according to criteria about the value or time of occurrence of the patient observation. Multiple observations can be included in the selection rule and the rule author can control the amount of data returned (one value from any of the observations, one across all observations or all values from across all observations). This type of flexibility is essential to accommodate special needs which develop.

Prompt rules

Prompt rules supplement selection rules. The rule author may link a prompt rule to a selection rule. If the selection rule finds no data about a particular observation, it can then execute a prompt rule. A prompt rule displays a simple form and asks the provider to enter data for a parameter. These data are validated against absolute and normal ranges and the user is warned about unreasonable or abnormal values. These data are then stored in the Electronic Medical Record (EMR) for subsequent use.

Special rules

All of the data needed for clinical decision support are not stored in the patient's EMR. Some information such as the patient's active orders are stored instead in the Gopher's order database. Using the R-BASIC language which is native to our application environment (Advanced Revelation©) data can be returned in structures which allow it to be manipulated just like any other G-CARE result.

Algebraic rules

Simple computations can be performed using algebraic rules. Each rule evaluates a single expression and returns a numeric result.

Logical rules

Logical rules also evaluate an expression but return a logical FALSE if the result of the evaluation is 0 or NULL and a logical TRUE if any other value results.

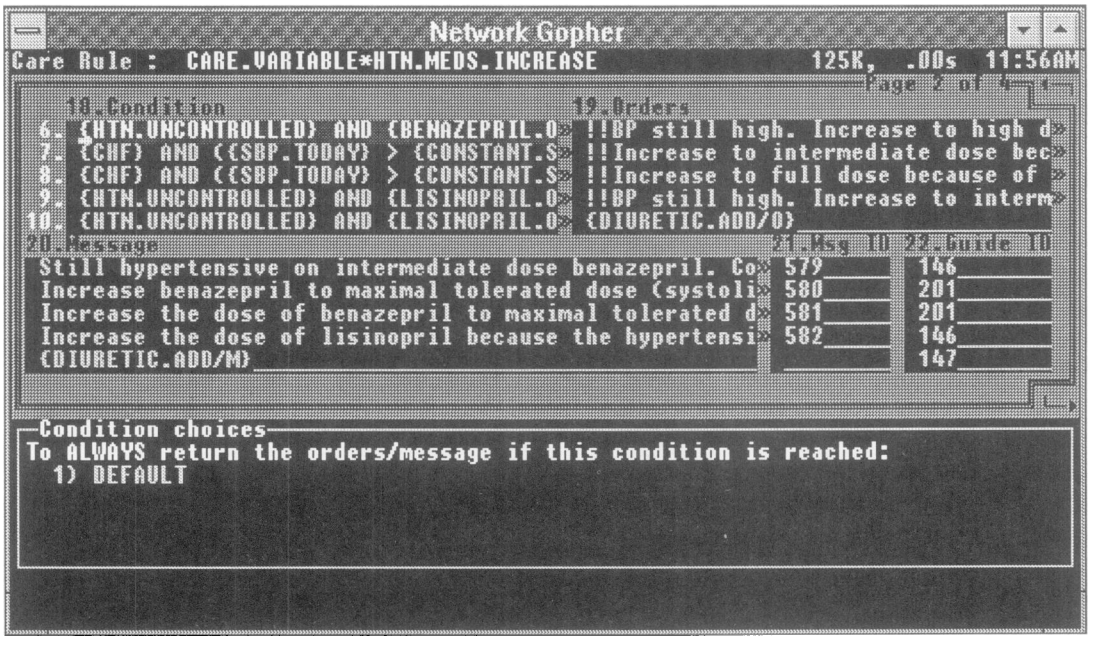

Figure 1 - Example of portion of a G-CARE reminder rule for escalating doses of antihypertensive drugs.

Reminder rules

Reminder rules are the most complex. They can return one of several reminder/order set pairs. Reminder rules include conditions and actions. The action can include a text message or a pre-written order. Both message and order can contain other G-CARE rules. The provider can accept the pre-written orders with a single click or keystroke. Which reminder/order set pair is returned is determined by the first condition in sequence which evaluates to TRUE. A condition called DEFAULT which always evaluates to TRUE may be included in order to ensure a reminder/order set pair is returned. A reminder/order set pair can include embedded G-CARE rules or be the result of other care rules. If the condition for this case evaluates to TRUE, then the embedded G-CARE rule is evaluated and the reminder and/or orders component returned.

Each reminder/order set pair can be assigned a message ID and a guideline text pointer. The former is a unique identifier for the particular case and the latter is an index into full text clinical guidelines. The guideline pointer allows the physician to display the relevant portion of a guideline - directly linking the recommended actions to a synthesis of the literature. Pointers to literature citations can be embedded in reminder text, messages/comments or comments within order sets. When one of these pointers is displayed on a workstation, the user can press a key to see the bibliographic citation.

Uses of care rules

G-CARE language rules can be inserted at a variety of points within or outside of the ordering process as shown below.

- new data is stored
- a patient is registered
- provider begins to write orders
- a term is selected to order
- choice lists are generated
- comment text is displayed
- a G-CARE rule executes
- an order is stored
- provider finishes writing orders
- reports are printed

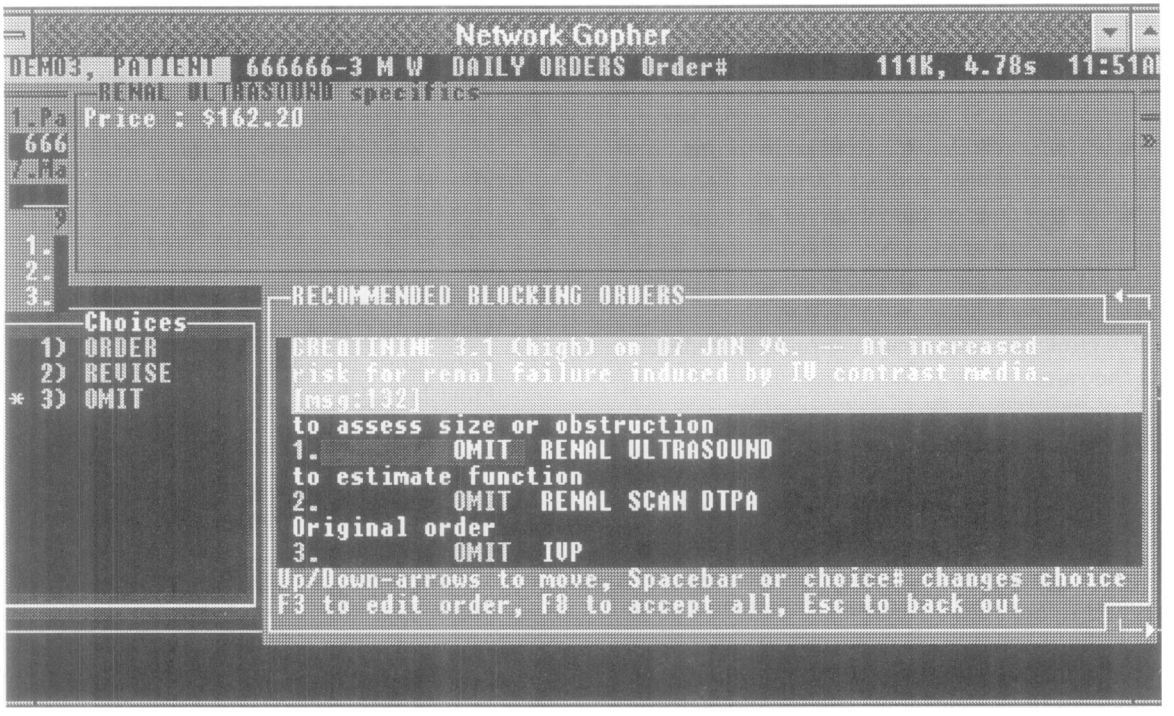

Figure 2 - Example of a G-CARE rule used as a blocking rule.

Representational power and complexity

Often, a single case in a G-CARE rule is adequate to implement reminders and alerts. Variations on this approach include (1) providing data about test results when the provider is ordering a test or treatment such as the most recent INR when ordering coumadin; (2) suggested orders for baseline testing or monitoring of treatments or diagnostic tests such as gentamycin serum levels when treating with that drug; and (3) blocking rules which provide suggestions for alternative tests or treatments when the item ordered by the provider is relatively or absolutely contraindicated. For example, we have a rule that suggests a nuclear medicine study to assess renal blood flow rather than an IVP in a patient with renal insufficiency (Figure 2).

Implementing practice guidelines or care paths is a more challenging task typically requiring multiple "layers" of rules to complete[13,14]. As an example, the AHCPR's guidelines for the medical management of patients with left ventricular heart failure required 164 rules with 347 cases in 5 layers to implement. Of these rules, nearly half were selection rules.

Performance

One limiting factor which we encountered was the execution time. Retrieving a result with a selection rule requires .26 seconds on average. Buffering of data can nearly eliminate this time. However, executing the guidelines for CHF, CAD, reactive airway disease, COPD and hypertension required 22 seconds per patient on an Intel '486 computer. To avoid putting this time burden on the physician writing orders, we execute these rules prior to patients' visits so that most of the results are pre-computed. We need only re-evaluate a few rules at order entry, dependent on new data obtained that day such a clinical observations (NYHA clinical class for congestive heart failure for example) or new laboratory results.

Readability

We adopted naming conventions which increased readability and added comments to the rules which explained their function to create reports which are easily read and understood by providers. Specifically, rules were named by the thing, usually a term from our clinical dictionary, they manipulated - diagnosis, drug, test result, part of the thing - dose, specimen, context - inpatient, outpatient, temporal limits -

last, next to last, last year. A rule might be named BENAZAPRIL.DAILY DOSE.OUTPATIENT.LAST to indicate the most recent total daily dose of enalapirl or NA.URINE.ACTIVITY.HIGHEST to indicate the highest urine sodium activity recorded whether inpatient or outpatient. Comments are simple text explanations of what the rule does, crafted to be readable when concatenated in other text. The availability of understandable reports allow clinicians to evaluate and provide feedback on the rules.

Planned Extensions

Based on our experience, two high priority areas for extensions to G-CARE are changes to improve performance and development of grouping mechanisms to reduce the combinatorial explosion of cases. Performance is borderline acceptable. In order to expand the number of guidelines implemented, we will need to increase performance considerably. We are attacking this problem by refining the anticipatory evaluation process to minimize the amount of evaluation required at order time further and by modifying the system architecture to eliminate some of the more inefficient parts of the evaluation process.

When multiple conditions are incorporated into a decision support system, many of the potential combinations of condition will result in different recommendations. Even for modest numbers of conditions the number of possible combinations is quite large - the combinatorial explosion. We have developed tools to manage this problem and have begun to incorporate them into G-CARE. Basically, we provide a mechanism for grouping orders together and placing specific conditions on each of them individually.

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