Formal Combinations of Guidelines: A Requirement for Self-Administered Personalized Health Education

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This paper addresses a process in which we combined educational guidelines (EG) from heterogeneous sources in one set of coherent computable statements to support dynamically generated and precisely tailored patient education material. The Guideline Interchange Format (GLIF), predicate logic and decision tables were assessed. An extended formalism of GLIF was applied to break up composite sentences of the educational material in atomic sentences. The differentiation of atomic sentences and combinations of atomic sentences from heterogeneous sources lead to a simplified overall content and model, and a significant reduction of conditional sentences in the EG. The resulting streamlined and personalized guidelines are expected to provide an improved user experience.

INTRODUCTION

There are fundamental differences between clinicians providing personalized education to a patient and education targeted to populations provided by public health agencies. Clinicians and health educators are trained to integrate knowledge and information from various sources, to present the relevant facts and information to patients; the dialogue takes into account bilateral feedback. Public health professionals design theoretically grounded education for targeted populations; their feedback is accrued during or after the intervention through formal sampling of the population. Such education targeting large audiences cannot be personalized with the same granularity as the clinicians' and health educator's interactive communications with a patient. Tailored Health Education administered by Information Technology (THE) provides the opportunity to draw together methods and theories from both disciplines.

Translation of a narrative guideline in computer-executable statements is complex and demanding. Scalable methodologies to integrate guidelines from heterogeneous sources have been developed, yet they presume independence of the eligibility criterion of the guidelines and have not provided insight in processes to formally resolve potential ambiguities and contradictions[1]. Decision table methods can detect inconsistencies, redundancies of individual guidelines[2] and test subsets of populations that can otherwise be omitted by clinical algorithm methods[3]. To our knowledge, such techniques have not been applied to combine sentences from heterogeneous guidelines sharing common domains of applicability. Furthermore, recent studies have shown considerable variation in guidelines representations[4,5] adding to the complexity of their combination. Fortunately, some techniques can link the apparent ontological gaps between domains thus providing a sound framework for guidelines development and maintenance[6].

The purpose of this study is to derive a formal framework to resolve the inherent complexity that results from merging relevant health education guidelines applicable to the same domain and to impart a coherent and uniquely personalized education experience to a patient. This paper describes the clinical and formal rationales supporting the development of THE. The tailoring of education material for the MI HEART Trial provided a test bed for this methodology.

METHODOLOGY

The education material produced in the course of the MI HEART Clinical Trial[7] (Myocardial Infarct - Health Education and Awareness for Rapid Treatment) served to test the validity of applying existing guidelines methodologies such as GLIF and Decision Tables to express computable education guidelines. A comprehensive description of the MI HEART Information Technology-based intervention and of its cognitive model is presented elsewhere[7].

The study of the mechanisms involved in merging guidelines were conducted according to the following steps:

1) We first delineated the domain of education using a taxonomic approach to the representation of the guidelines' intentions and of their content.
2) An extensive review of the literature was conducted to find the available educational guidelines in our domain of interest. The clarity, comprehensiveness, consistency, and potential

difficulties of implementation of the guidelines were assessed using recognized criteria from evidence-based medicine[8] and from medical informatics[9],[10].

3) Several guidelines were methodically analyzed, normalized, clarified, expanded in atomic sentences[2,11], differentiated and merged. Every step of the process of was carefully recorded and also analyzed. The usability of the GLIF[10] format was assessed as a canvas and improvements of representations of the guidelines were explored.
4) Formal logical processes were explored in order to systematically transform and merge the guidelines with reproducibility.
5) The results of the formal processes we appraised against the original guidelines.

RESULTS

Preliminary Observations

During the developmental phase of the MI HEART Study, the analysis of the educational material available for patients and their adaptation for computerized patient-administered tailored education lead to one observation:

I) GLIF needed to be adapted for use with education guidelines and tools to integrate education.

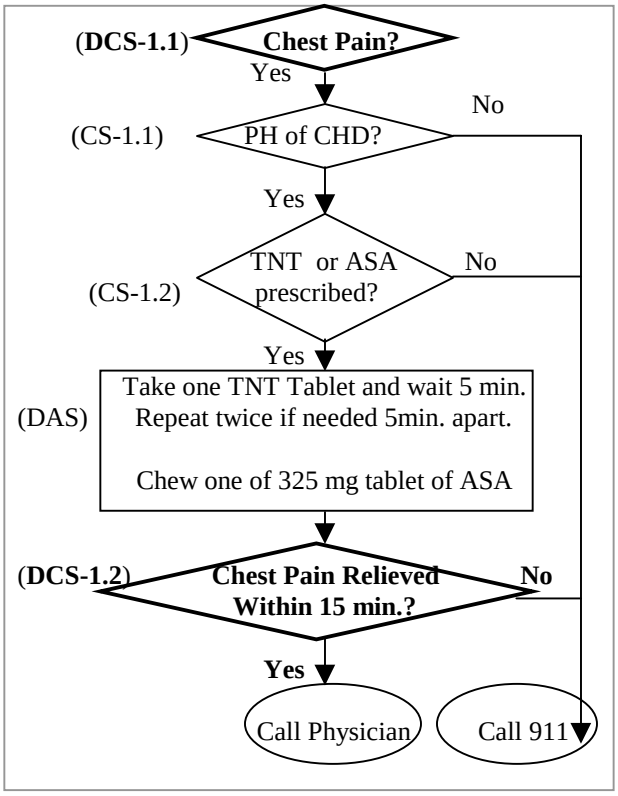
I Adapting GLIF's Notation to Support EGs

In GLIF, sentences can be expressed in term of 1) **Guideline Intention**, 2) **Eligibility Criteria** (EC), 3) **Conditional Criteria** (CC), 4) **Didactic Material**, 5) **Action Sentences** (AS) and other steps such as branch and synchronization steps. In EGs, we have observed all the previously mentioned elements with the additional elements: Didactic material also contains **Didactic Conditional Sentences** (DCS) and **Didactic Action Sentences** (DAS). Because of the similarities between actions and conditions that may be required by the patients and didactic material speaking of doing an action or thinking of a condition, the encoding of EGs is prone to some mistakes.

Figure 1 contains EG that is intended for a patient prior to experiencing Chest Pain. Thus the "Chest Pain?" condition is actually a didactic condition: it is intended for the patient to think about this condition. In contrast, the past history of coronary artery diseases (PH of CHD) is intended as a real condition to supply the relevant facts to the patient. The narrative version of this guideline requires the patient to think if this condition applies to him(her) and decide if the reading of the subsequent education material is relevant to his(her) condition. A computerized version of the guideline reading in the electronic record could automate this task.

The extraneous formalism of representing a narrative didactic statement has some advantages. For traditional guidelines, the use of a formal syntax for the representation of conditional expressions has been shown to be essential. Existing standards and tools such as syllogism, decision tables, propositional logic, and predicate logic can therefore manipulate the conventional criterion as well as the didactic criterion sentence. This formalism has been put to good use in our study since we intended to merge guidelines from different sources in order to improve the granularity and relevance of the tailored educational material. Furthermore, representing each step of the narrative content of an educational guideline can elicit grouping patterns across different guidelines thus reducing the complexity of the overall model.

Figure 1 Excerpt of the NHAAP Guideline[12]



Guidelines From the Literature Review

"Patient educational material destined to 1) clarify the symptoms suggestive of an AMI or unstable angina (UA) or to 2) educate on the actions to be taken in presence of these symptoms" was the overall framework linking the *guidelines intentions* of various EGs. The extension of the definition of symptoms of AMI to symptoms of AMI and UA provided a pathophysilogic framework in which we could query for diseases increasing patients risks of

presenting an AMI such as hypertension, diabetes, elevated cholesterol and smoking.

The review of literature provided over fifty EGs out of which eleven were grounded on sound evidence and merited further analysis (AHA[13], NHAAP[12], AHCPR[14], NKF[15], EHAC, ACC / AHA[16], AHA/ACC[17], NHBPEP[18], ICSI[19], PHE[20], ACEP[21]) . Only the first three previous EGs were considered amenable to a computable format. The eight rejected guidelines were considered intractably ambiguous in one of the following areas: "didactic condition criteria"(3/8), "eligibility criterion"(2/8) or "other didactic material" (2/8).

A Framework for Tailoring Guidelines

Table 2 presents a summary of a formal methodology that was followed to systematically and rigorously transform and expand all guidelines.

The *eligibility criteria* of the NHAAP and AHA guidelines targeted all patients, while the AHCPR EC was targeted to patients with a PH of any coronary heart disease (CHD) or having more than two risk factors (2R) of AMI (Diabetes Mellitus, hypertension, smoking, elevated cholesterol).

We derived a "normalized" medical terminology for the GI, CC and AS. For the Didactic Condition Criteria and the Didactic Action Steps we produced a "normalized" patient terminology. According to these terminologies, equivalent terms from different didactic content were standardized. For example, the terms "heart attack" would substitute all occurrences of the terms "AMI". We furthermore relied on taxonomical relationships to simplify certain condition criteria (for example: Asthma, chronic bronchitis and emphysema were subsumed by "chronic obstructive lung diseases").

For example, the AHCPR guideline contained specific instructions for exertional dyspnea (ED) as an anginal equivalent to chest pain (CP). We therefore substituted the symptom set "CP or ED" for all occurrences of CP in the AHCPR guidelines. Some guidelines, such as the NHAAP one, contain comments that are irrelevant for certain patients and these comments were annotated as conditional didactic material (for example, "*take a nitroglycerin if it has previously been prescribed*" does not need to be read by patients that do not have a prescription of nitroglycerin).

Finally, the expanded set of guidelines were merged according to decision table rules. Some atomic sentences were conflicting and necessitated expertise to resolve (for example, the NHAAP guideline advises to take nitroglycerin three time and to call 911 *after 15 minute of the onset of the symptoms*, while the NHCPR recommends *after 20 minutes of onset*).

Initially the guidelines addressed two groups of patients (anyone or patients at risk of angina). After expansion, simplification, differentiation and merging, the final set of guidelines were specialized for ten groups of patients comprising various clinical conditions such as angina, risks factors for CHD, COPD and usage of nitroglycerin. An interesting property emerged from the simplification of guidelines and the merging process: all guidelines were amenable to one meta representation: "warning symptoms of AMI were first described and then the actions to be taken in presence of these warning symptoms could be described" (one DCS leading to one DAS). The nested appearance of certain guidelines such as the one presented in figure 1 had been simplified. All CS that were read by all patients on the paper education form are hidden in the tailored format. As shown in table 2, this leads to a simplified and more relevant educational sentences (ES) experienced by the patient in tailored EG groups (TG) as compared to non-tailored (NT) one. Evidently, patients with more complex past histories (groups 2-9, table 1) have more educational material than individuals with no relevant conditions(groups 1, table 1). For example, the EG of group 4 are tailored for patients using nitroglycerin and with a history of angina pectoris.

Table 1 Complexity of the Educational Guidelines Experienced by Patients

Sentence Type	Number of Sentences per EG Group									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**NT**
Atomic (A) DCS	2	2	2	3	3	4	5	4	5	7
A DAS	2	4	4	4	4	4	4	4	4	4
Total A ES	**4**	**6**	**6**	**7**	**7**	**8**	**9**	**8**	**9**	**11**
Composite (C) DCS	6	6	6	8	9	12	14	12	12	16
C DAS	6	14	14	14	14	14	14	14	14	14
Total C ES	**12**	**20**	**20**	**22**	**23**	**26**	**28**	**26**	**26**	**30**

DISCUSSION

The formalism of the extended set of atomic GLIF sentences such as the didactic conditional steps and the didactic action steps clearly helped to simplify the complexity of the transformations needed to combine educational guidelines from heterogeneous sources.

Table 1 –Formal Methodology Developed to Produce Tailored Guidelines

Methodology	Clinical and Ontological Rationale and References	Examples from the MI HEART Clinical Trial
1. Define the clinical process that captures relevant Eligibility Criteria (EC)	A **Clinical Pathophysiologic Process Framework (CPPF)** describes the relationship between related clinical conditions, some of which can be chronic or periodical, while other are acute.	"Patient educational material destined to 1) clarify the symptoms suggestive of an AMI or unstable angina (UA) or to 2) educate on the actions to be taken in presence of these symptoms" was the overall framework linking the *guidelines intentions* of various EGs
2. Find relevant guidelines	Specialized guidelines are found through several clinical processes leading to a clinical condition based on. Select according to recognized criteria[8].	AHA[13], NHAAP[12], AHCPR[14]
3. Clarify Conditional Sentences (CS) and Actions(CA)	The administration of some guidelines may depend on some implicit or ambiguous CS, some conditions may be nested with specific action or advice according to the conditions.	"Take a tablet of nitroglycerin under your tongue as soon as you feel discomfort" is conditional to the CS "nitroglycerin previously prescribed"
4. Clarify the Didactic Conditional Sentences (DCS) and Actions (DAS)	DCS are communicated to the patient, while CS are not communicated but determine if the advice is communicated. As for the CS, some DCS may be implicit or ambiguous.	"Take a tablet of nitroglycerin as soon as you feel discomfort" becomes "Take a tablet of nitroglycerin as soon as you feel the *warning signals of a heart attack*"
5. Normalize the terminology of EC, CS, DCS, CA, DAS	**1) Synonyms:** Several guidelines might use synonyms for the same conditions. **2) Taxonomy**: Describes parent-child relationship between concepts. Normalization and consistency improves patient education, computability and maintenance of guidelines, CS and DCS.	1) Patient usage: AMI ➔ Heart Attack (HA) TNT ➔ nitroglycerine, ASA ➔ aspirin Symptoms of HA, Signs of HA ➔ Warning Signals of HA 2) Asthma is a Chronic Obstructive Pulmonary Disease (COPD)
6. Transform composite and nested guidelines in individual atomic guidelines with their associated CS,DCS, CA and DAS	Some clustered guidelines contain different educational material applicable according to different CS and DCS. The expansion of clustered or nested guidelines is done around the CS and DCS. Methods from natural language processing, syllogism, propositional logic or predicate logic can be used to disassemble complex clusters of DAS and ASs[22]: Example: $(p \vee q) \supset r \equiv (p \supset r) \vee (q \supset r)$	The clustered NHAAP guideline: "if you have warning signals of a HA and have a prescription of nitroglycerin, then (do Action 1). If the symptoms continue for more than 15 min. then (do Action 2)" becomes the following individual guidelines: 1) For patients with a prescription of nitroglycerin (TNT) (CS): "do Action 1". If the symptoms continue for more than 15 min then (do Action 2), 2) For patients without a prescription of TNT (CS): "(do Action 2)".
7. Expand Individual Guidelines with Alternate Content	**1) Updating**: Some new treatments or alternate forms of treatments may be available. **2) Inheritance–based Substitution:** Ontological inheritance allows the substitution of a general "parent" concept by a specific "children" one. **3) CPPF-based Substitution:** The disease process framework may allow to substitute some concepts within a guideline, a CS or a DCS with alternate concepts to produce new guidelines or guidelines in new contexts. There is one exception to the rule: CPPF-based Substitution can be applied only when the "alternate concept" or one of its "children concept" are not included in the proposition where it substitutes another concept.	1) Nitroglycerin tablet ➔ Nitroglycerin tablet or spray 2) "Because you have a COPD (…)" for a patient that specifically has asthma becomes "because you have asthma (…)". 3) In the context of patient with a past history of angina, *shortness of breath* (SOB) may be an "anginal equivalent". Thus, SOB is considered as equivalent to a thoracic pain in any guideline destined for patients suffering of angina. "Uncomfortable *pain in the center of the chest* may be a symptom of heart attack" ➔ "Uncomfortable *pain in the center of the chest or shortness of breath* may be a symptom of heart attack"
8. Group and *Clarify* the Guidelines according to CS	Represent all individual guidelines in a framework that allows for grouping around CS such as concept lattices or decision tables and "clarify".[23],[2]	-
9. Merge the Guidelines of a Group that shares the DCS	Individual guidelines are merged by using the same techniques as those used in "6. Transform clustered and nested guidelines". Avoid redundancies.	
10. Disambiguate	Some combinations of guidelines may lead to ambiguities or contradictions that may require the help of expert-clinicians to be resolved.	NHAAP: Call 911 after 15 minutes, AHCPR: Call 911 after 20 minutes

The number of conditions read by the patient was reduced for all groups of patients, regardless of the initial complexity of the conditions in the narrative format. Since the administration of the tailored EG is based on conditions that the computer can verify, conditional steps are removed from the narrative context and only the relevant text is presented to the patient. Furthermore, the final version of all guidelines amenable to one symptom set followed by one action set lead to simplicity to both the user of the system and improved its implementation and maintenance. This latter simplicity is attributed to the use of DCS and DAS during the transformation phases.

Conversely, merging the guidelines produced longer narrative education of the symptoms evoking an AMI for the patients with angina and using nitroglycerin. Indeed, none of the original EG would present explicitly the large variety of "anginal equivalent" symptomatology. Further studies will be needed in order to assess if this increased number of symptom sets can improve the educative relevance of the intervention or if there is threshold where added information loses significance.

CONCLUSION

GLIF extended with Didactic Conditional and Action Sentences formalizes the combinations of complex heterogeneous Educational Guidelines. Within the proposed framework, this leads patients to experience significantly more personalized, yet simpler, guidelines.

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