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157 East ELM Street, Unit A, Greenwich, CT 06830-6614, USA

E-mail: srwlv@1088.email

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An Ontologist Feedback Driven Ontology Evolution with an Adaptive Multi-agent System

Souad Benomrane [1,*], Zied Sellami [2], Mounir Ben Ayed [1]

[1] REGIM-Lab.: REsearch Groups in Intelligent Machines, University of Sfax, ENIS, BP 1173, Sfax 3038, Tunisia
[2] LIP6 – Equipe ACASA, 4 Place Jussieu, Boite Courrier 169, 75252 Paris Cedex 05, France
* Corresponding Author. E-mail: souad.benomrane@ieee.org

Abstract. In a dynamic environment, it is necessary to make changes to an ontology according to new knowledge and user needs. However, ontology evolution is still a complex and time-consuming task. In this paper, we presented OntoAMAS, an ontologist feedback tool based on an adaptive multi-agent system (AMAS) for ontology evolution. It consists of two components: (i) an AMAS (concept and term agents) that represents the current state of an ontology and (ii) a graphical interface which allows to manage the different interactions between the ontologist and AMAS proposals. First, we defined an adaptive behavior that enables agents to react to the ontologist's feedback. The ontologist gives his/her feedback (elementary and composite changes). He/She can also add new terms and concepts. Then, the AMAS self-organizes and produces an updated ontology with new proposals. It works in an interactive and iterative way until a satisfactory state of the ontology is achieved. Second, we proved that OntoAMAS guarantees that the adaptive skills we added to agents allow them to detect the uselessness of some proposals so as to avoid them together with the wrong ones and to propose others. The experimental results show the relevance of OntoAMAS and the effectiveness in time performance of its Protégé (ontology editor) GUI.

Keywords: Adaptive multi-agent system; Ontology evolution; Ontologist feedback.

1. Introduction

Ontologies developed and used for various applications have been increasing over the years. The major issue faced in ontologies is their change or evolution. Ontology evolution seeks to keep an ontology up to date with the changes of the domain it models, to new knowledge and user needs. These changes should be implemented in the ontology and should be managed in such a way that ensures to safeguard its consistency, structure and continuity across different versions of the ontology. Ontology evolution is a process that involves a number of steps, for which many techniques, tools and approaches might be needed [1]. In the literature, the majority of approaches tried to automatically perform one or two steps of the process to simplify the user's (ontologist's) task. However, throughout the evolution process stages, the ontologist was immediately involved. The ontologist chooses to apply the changes in the ontology, places the new entities (concepts, terms, relations), etc. However, manually evolving an ontology is a costly, complex, and time consuming process.

To the best of the authors knowledge, there are only two systems proposing an automatic ontology evolution namely EVOLVA and DYNAMO. The first [2] is only efficient for the evolution of English ontologies and has difficulties when the concerned domain is very specific. The second system was proposed by Ottens [3] as a first prototype of DYNAMO and then a new tool, called ≪ DYNAMO-MAS ≫ [4], was developed. DYNAMO prototype is based on an adaptive multi-agent system (AMAS) to co-construct and evolve ontology from texts. However, experiments [4] showed that linguistic clues are insufficient and claim that for the work to be more effective the intervention of an ontologist is required. An ontologist is a cognitive engineer using expert interviews and information from texts to construct ontologies.

In conclusion, ontology evolution needs to be more automated without ignoring the role of the ontologist especially during the validation step [5] and [6]. In this paper we aimed to answer two main questions: (i) How to improve the quality of evolution proposals (changes) by referring to the ontologist's feedback? (ii) How exploiting of the ontologist's feedback may reduce his frequent involvement? Therefore, our objective was to improve the results proposed by the AMAS by exploiting the ontologist's feedback. Consequently, improving the performance of AMAS may enable to reduce the frequent involvement of the ontologist.

By focusing on finding answers to solve the above mentioned challenges in ontology evolution, this paper contributes to the following key issues in two research areas: (a) Ontology Engineering, by proposing an extended approach [7] of an earlier work [4] in ontology evolution. Indeed, some improvements were achieved in the DYNAMO-MAS approach to better evolve the ontology by implementing some existing adaptive rules [4] and extending it with new adaptation behaviors added to the concept and term agents; (b) AMAS, by developing a tool called ≪ OntoAMAS ≫ that can be triggered when a new document is added to the corpus at any time or when the ontologist makes some improvements in the proposed results. OntoAMAS and the ontologist modify the same ontology in a cooperative and adaptive way: this process relies heavily on the strong relation between the action of one of them and the reaction of the other. The adaptation mechanisms added to the agents behaviors enable them to exploit the ontologist's feedback (elementary and composite changes) and self-adapt to personalize the OntoAMAS proposals. That is to say, we aimed to exploit the ontologist's feedback to personalize OntoAMAS proposals.

The remainder of this paper was organized as follows: Firstly, several related works on the existing approaches for evolving ontologies were described in Section 2, justifying the choice of AMAS for the management of ontologies and discussing the limitations of the current version of DYNAMO that led to the creation of OntoAMAS. Section 3, was devoted to the description of the OntoAMAS approach. The implementation of OntoAMAS was presented and the results were discussed in Section 4. Finally in Section 5, the paper major conclusions were drawn and some future works were suggested.

2. Related works

2.1. Ontology evolution

In the literature, ontology evolution appears as a part of a global scope of ontology maintenance. Stojanovic [1] defines ontology evolution as a process to ≪ adapt and change the ontology in a timely and consistent manner ≫. The process of ontology evolution contains 6 steps: (a) change capture, (b) change representation, (c) change semantics, (d) change implementation, (e) change propagation and (f) the validation. In order to manage these different tasks, several approaches propose: (i) tools and guidelines to capture change needs [8] or to identify new knowledge leading to some changes in the ontology [9] and [10]; (ii) models to represent these changes [1] and [11]; (iii) rules to identify the change semantics to avoid semantic inconsistencies that could occur as a result of these changes [1] and [12]; (iv) tools that implement changes [1] and [13]; (v) other studies ensure the propagation of changes and the update of applications and artefacts connected to the modified ontology [9], [14], [15] and [11]. Ultimately, evolution support tools and versioning were subject of discussion of many other approaches [13].

Several approaches and tools have been proposed in the literature [16]. Each tool seeks to automate one or two stages of the process. Stojanovic [1] was interested in a change representation phase where changes are represented following a specific model. This representation is followed by the change semantics phase, during which syntactic and semantic inconsistencies could appear as a result of changes. The KOANontology evolution tool [1] leads the formulation of changes by suggesting ontology improvements. Klein [9] and Rogozan [15] were rather interested in ontology versioning to manage the changes propagation in order to ensure the consistency of the underlying ontology and all dependent artefacts. Rogozan was inspired by the work of Klein and Stojanovic to propose an approach and a tool to manage the ontology evolution and versioning. To implement this approach, Rogozan [15] provides a tool consisting of two modules: ChangeHistoryBuilder and SemanticAnnotationModifier. Djedidi [12] focused on the steps of semantics of change and change validation. She proposes an approach and a prototype of evolution (Onto-Evoal: Ontology Evolution-Evaluation). It is an automated process driving the change application while maintaining the evolved ontology consistency. In addition, the tool integrates an evaluation activity supported by a defined ontology quality model. This model is used to guide inconsistency resolution by assessing the impact of the resolutions proposed by the evolution process on ontology quality and selecting the resolution that preserves the quality of the evolved ontology. Luong [14] focused on the stage of change propagation to the dependent artefacts namely semantic annotations. Tissaoui [11] focused on change representation step. He proposed an approach and a tool (EvOnto) that supports a coherent joint change management of (termino-ontologies or TOR) and semantic annotations by anticipating all the consequences of a change on the TOR and on the annotations. This allowed avoiding missing some of the impacts of a change.

It is worth noting, however, that the identification of change and changes representation are manual. The ontologist is often the one who is in charge of detecting the need to change the ontology and expresses this evolution. In general, throughout the evolution process stages, the ontologist was involved in each step. The ontologist chooses to apply the changes in the ontology, places the new entities (concepts, terms, relations), etc. It is a laborious process that requires a lot of time and effort. To minimize the frequent involvement of the ontologist, two solutions proposing an automatic ontology evolution from texts were addressed by two systems: EVOLVA[2] and DYNAMO[3].

EVOLVA [2] contributes in a unique way to the ontology evolution by analyzing the existing domain data, and being based on online ontologies as source of background knowledge for the enrichment step. Indeed, EVOLVA relies on these existing ontologies to seek a relation between the entity to be added to the ontology and the current ones already belong to the ontology. EVOLVA is relevant for the English ontologies since the majority of available ontologies on the Web are represented in English. Therefore, EVOLVA is less useful to enrich French ontologies. Experiments have also shown some limitations in EVOLVA when handling a very specific domain [5]. It has difficulties in detecting relations between a new entity and the already existing ones in the ontology.

The second system is the first prototype of DYNAMO [3] (an acronym of DYNAMic Ontologies). It is not able to evolve the ontology but it allows its construction from scratch. DYNAMO is based on an AMAS to construct and maintain an ontology. The agents of the AMAS implement a distributed clustering algorithm to identify clusters of terms from a large corpus of texts and organize these clusters into a set of concepts in a hierarchy. Each agent represents an extracted candidate term. Thanks to the statistical features, similar terms move closer to create and position concepts. The MAS evolves until all agents are hierarchically linked. The final state of the MAS corresponds to the ontology. The ontologist can then validate or reject. Experimentations carried out with this first prototype of DYNAMO confirmed the inefficiency of statistical approaches [5] when dealing with short texts.

To overcome the previous limitations mentioned in EVOLVA and in the earlier prototype of DYNAMO, DYNAMO-MAS [5] was proposed not as an evolution of the first prototype but as a new approach based on AMAS and using linguistic and statistical criteria. As our proposed approach is an evolution of DYNAMO-MAS, the next section is devoted to justify the choice of AMAS to represent the ontology and to present an overview of the second prototype of DYNAMO.

2.2. DYNAMO-MAS: adaptive multi-agent system for dynamic ontology

The main goal of DYNAMO is to reduce the need for manual interventions in building and evolving ontologies. Using an adaptive multi-agent system to manage ontologies is an original approach proposed by DYNAMO [6]. In the literature, whenever ontology and MAS are discussed, the role of the ontology in ensuring the communication between agents by sharing the same vocabulary is easily remarked. Various research works are interested in exploiting ontologies in MAS especially the Semantic Web [17], [18] and [19]. Nevertheless, the need to evolve ontologies highlights new challenges. Some studies have used MAS for ontology evolution [20] and [21]. The MAS is used as a tool to seek knowledge and ensure the consistency of the ontology [22]. The MAS was used for the first time as an ontology in DYNAMO project [3] and [23] and then in DYNAMO-MAS [5]. Several adaptive techniques (Genetic Algorithm, Artificial Neural Network, Support Vector Machine) [24] are available but not effective in our case where the environment is open and dynamic (addition of new knowledge, actions of the ontologist) for the following reasons:

—In a genetic algorithm, a population of candidate solutions (individuals) evolves toward better solutions to an optimization problem. In our case of ontology evolution, the search space of the best solution is represented by all possible settings of ≪ n ≫ individuals. Initially, ≪ m ≫ random solutions are generated. Then, to achieve the best solution, the ≪ m ≫ solutions are mutated, altered and selected. Commonly, the algorithm terminates when a satisfactory fitness level (function of evaluation) is reached for the population. Unfortunately, in ontology evolution, it is impossible to give a reliable quantification function that can assess the quality of an ontology. Furthermore, a genetic algorithm is time and memory space consuming. Our goal was to help the ontologist to rapidly evolve an ontology. The use of such algorithms would not be suitable.

— In the context of the problem of ontology evolution from texts, a Neural Network could represent a set of functions-rules that allow the evolution of an ontology from any text belonging to the domain of this ontology. For example, a set of neurons could model a function that describes how and when a candidate term is transformed into a term or a term into a concept, etc. However, the learning phase of such a system would require thousands of ontology evolution examples, which is not feasible in the context of our problem.

—A Support Vector Machine (SVM) requires a large amount of samples to represent a class. However, in our case, this technique would not be effective because we are working in a small amount of data in the corpus.

Therefore, we need an adaptation technique that overcomes these limitations. Following the observations of natural phenomena, an emerging system consisting of a set of entities that interact and self-organize seems to be the appropriate solution to our problem. To define this technique we relied on the adaptive multi-agent systems paradigm that enabled the design of an adaptive system using the emergent functionality.

The underlying reasons for the choice of AMAS are both the properties of the environment where the ontology evolves and the qualities offered by AMAS. Ontology evolution is a complex problem incompletely specified nor does an a priori known algorithmic solution exist. The organizational skills of the AMAS ensure a permanent local self-adaptation to the dynamicity of the environment [25]. Each autonomous agent has a local view and uses perception of its environment to make decisions about actions to take. According to the proper rules to pursue and the local objective to achieve, the agent can adjust its cooperative interactions with other agents to finally lead to a common result [26]. AMAS also allows an easier interactive design of a system. In fact, It enables an incremental construction of the ontology by taking into account new data and new user’s needs (the ontologist revises his/her choices according to current results at any time). Indeed, the adaptation is guaranteed by AMAS. Designing an AMAS consists in defining and assigning cooperation rules to agents. The problem to solve in our case is to ensure the consistency of the ontology during the evolution process. Therefore, the designer has to (i) define the nominal behavior of the agent, (ii) deduce the Non Cooperative Situations (NCSs) or exceptions [4] which the agent may come across, and finally (iii) define the actions the agent must perform to come back to a cooperative state and to self-adapt to the environmental dynamics and to the ontologists actions. This self-adaptation of an agent is implemented through three behaviors: the nominal behavior directly related to the partial function of the agent that contributes to the overall emerging function; the cooperative behavior which includes the detection and the resolution of NCS as well as the anticipation and the prevention of the occurrence of NCS; the adaptive behavior which allows the agents to react to the ontologist’s actions towards the AMAS proposals. These modifications are considered as a local disturbance by the concerned agents and therefore an inconsistency of the ontology. Adding the adaptive skills may help these agents self-adapt and find their right location inside the ontology again.

Using a MAS to represent an ontology is an originality of the DYNAMO project. In recent years, two approaches have been proposed to manage and maintain Terminological and Ontological Resources (TOR): (i) EvOnto [11] and [27] that support a coherent joint change management of ontology and semantic annotations where the ontologist is involved to choose the appropriate scenario to apply the list of changes and (ii) DYNAMO-MAS [5] and [28] an adaptive MAS based TOR evolution, used to represent the ontology itself and to produce the ontology, as well.

First, DYNAMO-MAS takes a set of relevant candidate terms and lexical relations as input (Hyperonymy, Meronymy, Synonymy, transverse relations). These very candidates were the results of a corpus analyzer carried out by a term extractor YaTea [29] in the form of triplets (Ti, Rel, Tj). Each triplet has a confidence (Q,I): Q is the quality of the relation(Rel) and I: is the number of relation instances in the corpus. Then, these candidate terms will be agentified and added to DYNAMO-MAS which already has an ontology and contains two types of agents: (i) term agents that represent the terminological component of the ontology and (ii) concept agents representing the conceptual part. During their life cycles, the agents are locally seek their right place inside the ontology. Finally, DYNAMO-MAS generates a new ontology draft as well as a set of proposals as an output to be validated by the ontologist.

2.3. Discussions

To sum up, DYNAMO-MAS was a tool that reacts when new document was added to the corpus. A nominal and cooperative behavior was implemented in each type of agent on how to react to pieces of information received from other agents and how to communicate with them. Each agent has a set of parameters and knowledge enabling the MAS self-organization. The term and concept agents aimed at finding their “right position” (the one that optimizes some of their parameters) in the MAS. In order to propose itself to be part of the ontology, the agent computes its relevance value according to a formula (shown in the Section 3.4). However, the previous work does not take into account the impact of the ontologists actions. In DYNAMO-MAS, experiments [4] showed that linguistic clues are not enough to decide the content of an ontology and that the ontologist has a fundamental role in the ontology evolution process. However, the different reactions of the ontologist towards the AMAS proposals are considered as disturbance by the DYNAMO-MAS. To resolve this problem, exploiting the ontologist’s feedback seems to be very relevant. Therefore, an extended approach of DYNAMO-MAS called ≪ OntoAMAS ≫ was proposed consisting in personalizing the AMAS output with the actions of the ontologist (who can be more or less strict: non-static feedback [4]) in order to update the current representation of the ontology.

The originality of our system is to ensure the consistency of the ontology without the frequent involvement of the ontologist. It can be seen as a virtual ontologist that helps the ≪ real one ≫ to carry out an ontology self-adaptation and evolution. The ontologist only acts to give his/her reaction towards a proposal. It is an entire automatic adaptation contrary to [11] and [30] approaches where the ontologist gives his/her reaction and the system guides him/her, by proposing the possible evolution strategies, to finally choose the relevant scenario to apply the list of changes.

Table 1 summarizes and shows a comparison of our proposed approach with the previous presented approaches for ontologies evolution. The comparison is based on the following criteria:

— Ontologist actions: represents the different reactions of the ontologist towards the system proposals;

— Feedback ontologist exploit: means that the system takes into account the modifications generated by the intervention of the ontologist in order to update the internal representation of the ontology;

—Automatic adaptation: means that the system adapt to the ontologist’s feedback by determining automatically the appropriate strategy to apply the list of changes;

— iterative process: means that the process of validation and reorganization of the ontology is repeated and ends when the ontologist is satisfied by the modified and consistent ontology;

—Graphical user interface (GUI): means the efficiency of the GUI design in minimizing the time spent to construct the final draft.

3. Proposed approach: OntoAMAS tool for ontology evolution

3.1. Case study

OntoAMAS is a part of DYNAMO (DYNAMic Ontology for information retrieval) project. Our contribution in this project was to propose a method and a tool that allow the evolution of Terminological and Ontological Resources (TOR) from a textual documents corpus in order to facilitate the semantic information retrieval driven by user satisfaction in a dynamic context. A TOR is a resource that consists of a conceptual component (an ontology) and a lexical component (a terminology) [31] and [32]. In fact, a TOR covers not only a set of domain concepts but also a set of associated terms (their linguistic manifestations in documents: each term ≪ denotes ≫ at least one concept). These terms are used to annotate documents in order to facilitate semantic information retrieval within the corpus. The TOR (called ≪ ontology ≫ in the rest of the paper) is formalized using the OWL-based TOR model provided by a partner of the DYNAMO project [33]. The used TOR is a meta-model in which the OWL ontology concepts and associated terms are OWL classes. A ≪ concept ≫ class is denoted by one or more classes (terms). Symmetrically, a ≪ term ≫ class must necessarily have a denotation link toward a concept class.

To avoid the confusion between term and concept we resorted to an example. The concept (Car) can be materialized in the mind as an abstract representation of a bodywork with wheels, a steering wheel, windscreens, etc. This idea can also be achieved as a private car (eg. car Mr. X or black Peugeot of the neighbor, etc.). It is an instance of the concept. To express this concept, we use linguistic forms (words) such as (auto), (car), (jalopy), etc. Thus, the terms serve as means to express concepts.

—A concept: is a general, abstract and mental representation of an object. It can be expressed by a term, symbol or others. Thus, the terms represent linguistic expressions of real or immaterial objects that share common properties. Concerning the concept/instance relation, it is similar to that of class/object. The instance is thus a particular object in the world or a member extension of a concept.

—A term: is a meaningful unit consisting of a word (simple term) or more words (complex term). It identifies a concept uniquely within a domain. A term makes sense in its particular area of application. The same term takes one or more meanings according to the fields (polysemic) or even within the same domain.

One of the most important features of the DYNAMO project is to take into account the potential dynamics of the searched document collection, of the domain knowledge as well as the user's needs evolution. The document collections represent task-oriented technical documents. They have a reasonable size (a few hundred documents) that enable the user to manage them and check their annotation. Our project does not aim at dealing with very large web-extracted corpora.

Our specific interest was to develop a tool that allows the system and the ontologist to modify the same ontology in a cooperative and adaptive way. This process relies heavily on the strong relation between the action of one of them and the reaction of the other. The core of our work was to model an AMAS based tool called ≪ OntoAMAS ≫ designed with ADELFE methodology [34].

3.2. OntoAMAS architecture

OntoAMAS approach for ontology evolution is an iterative and interactive process. It contains 4 main modules (Fig. 1):

—module 1: Adding new documents to the corpus. When new texts are added, new knowledge appears containing new terms and their corresponding concepts.

—module 2: Extraction and filtering of terms and lexical relations. The addition of a new text to the corpus triggers the corpus analyzer which prepares the inputs for MAS. The corpus analyzer includes a term extractor named YaTeA [29], a lexical relation generator and a term and lexical relation selector. The corpus analyzer generates triplets (Ti, Rel, Tj) where Ti and Tj are candidate terms or terms (whether the term belongs or not to the ontology) and Rel is a lexical relation. Each triplet has a confidence (Q, I) where Q is the quality of the relation (value between 1 and 10) and I is the number of instances of the relations in the corpus. The triplets are the inputs of the MAS.

—module 3: OntoAMAS: Knowledge interpretation, ontology updating and self-adaptation to the ontologist's feedback. It corresponds to the first main module of our work. Thanks to the extracted lexical relations or to those existing in general ontology, each new term has to be linked to a concept that already exists or that will be created in the current ontology by a denotation relation. Each entity (term/concept) is associated to an agent and has a confidence value (more details in the next part) varying along the self-organizing process. Thus, the most relevant new concepts and terms will be proposed to the ontologist. These agents act according to their nominal and cooperative behaviors to determine their ≪ adequate position ≫ (the one that enables the optimization of their parameters) in the organization of the AMAS and enhanced with the adaptive behaviors to self-adapt to the ontologist's feedback towards the proposals given by the AMAS. The MAS constitutes, therefore, the resulting ontology.

In this module, OntoAMAS enhances the nominal and cooperative behaviors already defined in DYNAMO-MAS [24] by (i) implementing some existing adaptive rules (adaptation to acceptance, rejection and moving) and (ii) extending them with new behaviors of adaptation towards elementary and composite changes applied by the ontologist (developed in details in Section 3.4).

—module 4: GUI: The ontologist interventions. It corresponds to the second main module of our work. It is an interface, implemented in the Protégé ontology editor, enabling the ontologist to visualize and control the MAS proposals. Through this interface, the ontologist expresses his/her intention to modify the resulting propositions by applying elementary and composite changes (accept, reject, move, delete, create, split, merge, group, etc.). The adaptation mechanisms offered by the MAS enable OntoAMAS to better adapt its results to the ontologist's feedback. This interaction is repeated until a satisfactory state of a consistent ontology is obtained.

Our work focused on the instantiation of AMAS approach to the issue of ontology evolution. Therefore, The remainder of the paper was devoted to present the characteristics of OntoAMAS and GUI. In the DYNAMO-MAS approach, the AMAS trigger was the enrichment of the corpus by adding new text while in our case, the trigger is both the added document and the intervention of the ontologist by expressing his/her reactions towards OntoAMAS proposals.

The two noticeable difference between our work and DYNAMO-MAS are highlighted in Fig. 1 with blue1 dashed lines.

3.3. The fundamental role of the ontologist

The aim of our work is to personalize the results provided by OntoAMAS with the ontologist actions. These actions can be a set of reactions to OntoAMAS proposals or personal suggestions specific to the ontologist. He/She can apply two types of changes: elementary changes and composite changes. Stojanovic [1] defines an elementary change as an ontology change that modifies (adds or removes) only one entity of the ontology model and a composite change as a change of ontology that can be decomposed into several elementary changes. The ontologist can also manually add new concepts and terms and modifies the location of some entities of the ontology. These actions of change require different ontology evolution strategies depending on several criteria. The role of OntoAMAS is to find ≪ automatically ≫ the adequate strategy thanks to the mechanisms of adaptation allowing agents to self-adapt to the ontologist's feedback. OntoAMAS is based on the declarative approach of Stojanovic [1]. This approach does not present in advance the possible strategies for solving change operations. The ontologist expresses declaratively his/her intention (What) and OntoAMAS executes the relevant evolution strategy (How) to respond to ontologist's needs. So, the ontologist only acts to give his/her reaction towards a proposal which argues the rareness of ontologist involvement. The Table 2 shows the types of evolution changes applied in our approach.

The modifications carried out by the ontologist are considered as a local disturbance by the concerned concept/term agents. Therefore, thanks to the added adaptive behavior to these agents, they will self-adapt and find again their right location inside the ontology.

3.4. Agents adaptive behavior in OntoAMAS

Each agent in the OntoAMAS represents a concept or a term and its autonomous and cooperative behavior is to find its appropriate place in the organization, namely in the ontology. Each agent possesses communication skills and adaptive behaviors to modify and structure the ontology according to different rules. OntoAMAS output is the ontology obtained from the interaction between agents, while taking into account the ontologist feedback [7] when he/she modifies the ontology according to his/her expertise or the application requirements. It is a construction process where OntoAMAS and the ontologist interact in real-time depending on their respective knowledge. In this section, we present the different consequences of evolution changes on the ontology, and the reactive and adaptive behaviors of agents.

3.4.1. Term agent adaptive behavior

A term agent has a status indicating whether it is part of the ontology (valid term agent) or it is at the proposal stage (candidate or an invalid term). Each term agent has to be related to at least one concept agent. It is also connected to other term agents according to the extracted lexical relations from the corpus. Each relation between term agents is characterized by the confidence value of the triplet (Ti, Rel, Tj). The term agent has three types of behavior: nominal, cooperative and adaptive behaviors. The aim of a term agent is to find its appropriate position in the MAS to finally propose itself to the ontologist. To reach its goals, it has to respect the following rules allowing some local organizational modifications:

—Rule 1: each term agent has to denote at least one concept.

—Rule 2: it treats all its lexical relations and the different requests coming from other concept and term agents.

—Rule 3: a term agent computes its confidence or relevance value (varying between 0 and 10). When this score exceeds a threshold (fixed to 5 but adjustable), the term agent can propose itself to the ontologist. The ontologist can vary this threshold. At the beginning of the evolution process, it starts with a low value (to get several suggestions) and when the ontology offers good annotations of the corpus documents, this value increases.

The adaptive behavior: the ontologist intervenes to revise the OntoAMAS proposals by applying one or more evolution actions enumerated above and the concerned agents will adapt according to their adaptive skills. Therefore, the OntoAMAS reorganizes the agents, improves the already made proposals and proposes others to generate a new ontology proposal.

In total, 5 adaptive behaviors were added to each term agent (adaptation to acceptance, rejection, removing, moving, new term creation). Below, a descriptive example for each term agent adaptive behavior was presented.

Adaptation to acceptance or rejection: To ensure the self-adaptation of a term agent to ontologist acceptance or rejection, we enhanced it with the following behaviors.

When the ontologist accepts or rejects a term agent, the latter sends a message to its neighbors (agents with whom it already has interacted) but not yet validated to inform them. Therefore, they recalculate their relevance value (between 0 and 10).

For example (Fig. 2), when the term agent Problem is accepted or rejected, it informs its neighbors: Problem FailureFull-size image (<1 K). This message enables it to update its knowledge and recalculate its relevance value (can be adjusted throughout the evolution process). If it exceeds the threshold (fixed to 5) and respects the ≪ Term Proposal Condition ≫ (TPC), it proposes itself to be part of the ontology.

TPC: a term agent cannot be proposed if the concept it denotes has not be proposed first. When a concept agent is rejected, then its term agents (not yet proposed) wait until the concept agent proposes itself again.

Adaptation to a new term creation: When the ontologist proposes a new term agent to be associated with a concept agent, it sends a denotation request containing its label. The concept agent accepts and notifies the term agent. Therefore, it informs its neighbors not yet validated by sending a message. They recompute their relevance values. If they exceed the proposal threshold, then, they may be proposed to the ontologist.

Adaptation to removal: When the ontologist proposes to remove a term agent, it informs its neighbors not yet validated (term agents and concept agents) by message. They recompute their relevance values. If they exceed the proposal threshold, then, they can be proposed to the ontologist.

If the concerned term agent is the only term that denotes its concept agent, then this concept will disappear automatically from the AMAS (Execution of the concept agent adaptation behavior to removal). Otherwise, the concept agent will choose a new term agent to denote it and then determines its new label. The preferred term agent is the one having the denotation link with the highest weight.

Adaptation to moving: When a term agent is moved by the ontologist, it informs its neighbors not yet validated, by sending a message. For example, if the term agent (Data Failure) is moved, then it sends a message to the concept agent (Data Failure) and the term agent (Problem Failure).

The term agent (Data Failure) moves to the concept agent (Failure) to denote it Full-size image (<1 K) (Fig. 3). If the concept agent (Data Failure) is already proposed then it will be removed automatically.

If the term agents (Data Failure) and (Problem Failure) are related with a synonymy relation (Data Failure target) then the term agent (Problem Failure) computes its relevance value. If the moving of (Data Failure) to (Failure) increases the relevance of the term agent(Problem Failure) then (Problem Failure) moves to the concept agent (Failure) Full-size image (<1 K).

If there is hyperonymy relation between (Data Failure) and (Problem Failure), then the term agent (Problem Failure) sends a request to the concept agent (Failure) asking for its parent concept agent Full-size image (<1 K). The concept agent (Failure) processes the request and notifies the term agent (Problem Failure) by a message containing his parent concept agent (Default) Full-size image (<1 K). (Problem Failure) sends a request to (Default) to establish a denotation link. (Default) accepts and sends a notification to (Problem Failure). Therefore, (Problem Failure) moves to (Default) to create a denotation link with it Full-size image (<1 K). If the concept agent (Problem Failure) has already proposed then it will be removed automatically.

Adaptive term agent relevance value: OntoAMAS has to learn how to automatically adjust the agent relevance value according to ontologist actions. In fact, the ontologist can be more or less strict. For this reason, we propose to add a new parameter to the formula of relevance value called "Strictness Degree" (Stdegree). We consider that over time, the stricter the ontologist is and refuses proposals, the less luckier the non-proposed ones become to be proposed and therefore the value of Stdegree increases and the agent relevance value has to be decreased. Inversely, the more the ontologist accepts proposals, the more the non-proposed agents could be considered as interesting. Consequently, the relevance value has to be increased by reducing the Stdegree.

Thus, we propose to adjust the Stdegree parameter after a given number of successive ontologist feedbakcs. This adaptation mechanism was implemented with the following formula:

where P1 is the highest relevance value of its lexical relations, P2 represents the quality of its term agent neighbors (valid or not yet); P3 corresponds to the status of its lexical relations (accepted or refused); P4 indicates the diversity of the lexical relations of the term agent. After various experiments with DYNAMO-MAS [5] the values empirically fixed as follows: $\alpha1\alpha1 = 0.5$, $\alpha2\alpha2 = 2$, $\alpha3\alpha3 = 2$ and $\alpha4\alpha4 = 1$. These values best weighed the parameters of the agent relevance.

Initially Stdegree = 2; the Coef value varies according to the ontologist feedback:

—if the ontologist accepts the term agent then

where P1 is the highest relevance value of its lexical relations, P2 represents the quality of its term agent neighbors (valid or not yet); P3 corresponds to the status of its lexical relations (accepted or refused); P4 indicates the diversity of the lexical relations of the term agent. After various experiments with DYNAMO-MAS [5] the values empirically fixed as follows: $\alpha1\alpha1 = 0.5$, $\alpha2\alpha2 = 2$, $\alpha3\alpha3 = 2$ and $\alpha4\alpha4 = 1$. These values best weighed the parameters of the agent relevance.

Initially Stdegree = 2; the Coef value varies according to the ontologist feedback:

—if the ontologist accepts the term agent then

where TermAgRelevance is the current relevance value of the concerned term Agent and Threshold is fixed to 5.

After 10 successive ontologist actions, OntoAMAS starts supervising his/her behavior.

—If the number of acceptance actions exceeds the number of rejection or removing actions, the TermAgRelevance has to be increased by adjusting the value of Stdegree, Stdegree = 3.

—If the number of rejection or removing actions exceeds the number of acceptance ones, the TermAgRelevance has to be decreased by adjusting the value of Stdegree, Stdegree = 1.

—Otherwise, Stdegree keeps its initial value, Stdegree = 2.

3.4.2. Concept agent adaptive behavior

As mentioned in Section 3.4.1, the concept agent also has three types of behavior: nominal, cooperative and adaptive behaviors. The nominal and cooperative behaviors were summarized in the following rules:

—Rule 1: each concept agent has a status indicating whether it is a candidate concept (at proposal stage) or not (part of the ontology). It has conceptual relations with other concept agents and linked to term agents with a denotation relation. Each conceptual relation has a status indicating whether it is processed, non-processed or rejected relation.

—Rule 2: to define its favorite label (the label of the term having a the denotation link with the highest relevance value).

—Rule 3: if its relevance value exceeds the threshold, it proposes itself to the ontologist.

The adaptive behavior: according to its adaptive skills, the concept agent self-adapts to ontologist actions enumerated in Table 2.

In total, we added 9 adaptive behaviors to each concept agent (adaptation to acceptance, rejection, renaming, removing, sub-concept creation, moving, merging, split, grouping).

A descriptive example was presented below for each concept agent adaptive behavior.

Adaptation to an acceptance: When a concept agent is accepted by the ontologist, it informs its neighbors not yet validated by sending a message. This message allows them to recompute their relevance values. For example, when the concept agent Failure is accepted, it informs the term agent Failure, the concept agents Data Failure and Problem Failure of its acceptance Full-size image (<1 K) (Fig. 4). Therefore, each agent recalcultes its relevance. If it exceeds the proposal threshold and it respects the Term Proposal Condition and the Concept Proposal Condition (CPC), then it proposes itself to be part of the ontology.

CPC: A concept agent cannot be proposed unless its concept parent has already been suggested.

Adaptation to rejection: When a concept agent is rejected, it prevents its other linked agents. Since the concept agent has a cooperative behavior, it proposes a new concept parent to its invalid neighbors agents. It can be either its concept parent agent or the TOP concept agent. The concept agent chooses to propose the one that has the highest relevance value. A valid concept agent is more effective than TOP concept agent and the TOP concept agent is more relevant than an invalid concept agent that has not exceeded the threshold of relevance.

Thus, the rejected concept agent informs its neighbors not yet validated by sending a message including their new parent concept agent. Upon receiving this message, a concept agent recomputes its relevance value. If it exceeds the threshold proposal, it moves to the new parent concept to be able to propose itself. For example, when the concept agent Failure is rejected by the ontologist, it sends an information message of rejection to the concept agents Data Failure and Failure Problem and the term agent FailureFull-size image (<1 K) (Fig. 5). These agents recompute their relevance. The concept agent Data Failure exceeds the proposal threshold. Then it sends to the concept agent Default a request for establishing an (is-a) relation Full-size image (<1 K). The latter accepts and sends to Data Failure a notification message Full-size image (<1 K). Upon receiving this message, the concept agent Data Failure creates a new conceptual relation with the concept agent DefaultFull-size image (<1 K) and removes its old relation with the concept agent FailureFull-size image (<1 K). Therefore, the concept agent Data Failure can propose itself to the ontologist.

Adaptation to renaming: When the ontologist proposes to rename a concept agent, the AMAS automatically creates a new term agent with the same label to denote the concept agent. The new term sends a denotation request to the concept agent and the latter accepts and notifies it. Then, it informs its neighbors,not yet validated, by message containing its new label. They recompute their relevance values. If they exceed the proposal threshold, then they can be proposed to the ontologist.

Adaptation to removal: When the ontologist proposes to delete a concept agent, it informs its neighborhood, not yet validated, by sending a message. This message allows them to recompute their relevance values.

For example, if the concept agent (Failure) has to be removed, it informs its neighborhood: the term agent (Failure), its sub-concept agents (Data Failure) and (Problem Failure) and the concept agent

(Exception) and it proposes a new parent concept agent (Default) Full-size image (<1 K) (Fig. 6). The concept agents (Data Failure) and (Problem Failure) and the term agent (Failure) recompute their relevance values. If they exceed the proposal threshold, then, (Data Failure) and (Problem Failure) send a request to establish an (is-a) relation with (Default) and the term agent (Failure) sends a denotation request to (Default) Full-size image (<1 K). The latter accepts and notifies them. Therefore, (Data Failure), (Problem Failure) and the term agent (Failure) move to (Default). The concept agent (Failure) has no more a term to denote it. Thus, it disappears from the AMAS. Otherwise, the concept agent (Failure) will disappear with their sub-concept agents (they have no more parent concept agent) from the AMAS. If the relevance score of the concept agent (Exception) exceeds the threshold, then it may be proposed to the ontologist.

Adaptation to a sub-concept creation: When the ontologist proposes to create a sub-concept agent, AMAS automatically creates a term agent that has the same label as the new sub-concept. The term agent sends a denotation request to it and the latter accepts and notifies it. Then, the sub-concept agent sends a request message to its parent concept agent to establish an (is-a) relation. The latter accepts and notifies it. Then, it informs its neighbors, not yet validated, by sending a message containing its label and its status (valid). it recomputes its relevance value. If it exceeds the threshold, therefore it may be proposed to the ontologist.

Adaptation to moving: When a concept agent is moved by the ontologist, it informs its neighbors, not yet validated, by sending a message.

For example, the concept agent (Exception) has to move to be a sub-concept of (Default). Thus, it informs the term agent (Failure) and the concept agents (Data Failure) and (Problem Failure) Full-size image (<1 K). Then, it sends a request to establish an (is-a) relation to (Default) Full-size image (<1 K). The concept agent (Default) accepts this request and notifies (Exception) Full-size image (<1 K). Therefore, (Exception) creates an (is-a) relation with (Default) (Fig. 7).

The concept agents (Data Failure) and (Problem Failure) and the term agent (Failure) recompute their relevance values with the intention to move to (Default). If the relevance exceeds the threshold, then, (Data Failure) and (Problem Failure) send a request to establish an (is-a) relation with (Default) and the term agent (Failure) sends a denotation request to (Default). The latter accepts and notifies them. Therefore, the term agent (Failure), (Data Failure) and (Problem Failure) move to (Default). The concept agent (Failure) has no more a term to denote it. Thus, it disappears from the AMAS.

Adaptation to merging: When the ontologist proposes to merge a concept agent with a validated one, the AMAS reacts and adapts to this action by running a set of operations.

For example, when the ontologist proposes to merge the concept agent (Exception) with the validated concept agent (Failure), (Exception) informs its sub-concepts agents (DB Exception) and (System Exception) and the term agent (Exception Error) by sending a message containing the new suggested parent concept agent (Failure) Full-size image (<1 K) (Fig. 8). (DB Exception), (System Exception) send a request message to (Failure) to establish an (is-a) relation and (Exception Error) sends a denotation request Full-size image (<1 K). If their new relevance values(with the new parent concept) increase, then the concept agent (Failure) notifies them by sending a message of acceptance Full-size image (<1 K). Therefore, (DB Exception), (System Exception) and (Exception Error) move to (Failure).

If (Exception) has no more sub-concepts or term agents then it disappears automatically from the AMAS otherwise it will be removed, necessarily, by running the removal concept operation (detailed in section Adaptation to concept removal).

Adaptation to split: When the ontologist proposes to split a concept agent, the AMAS automatically creates a new concept agent and associates it to the same parent concept agent. For example, when the ontologist proposes to split the concept agent Component, it creates a new concept agent.

Component proposes to its sub-concepts to move to the new one by sending a message Full-size image (<1 K) (Fig. 9). This change operation generates a Non Cooperative Situation of ambiguity (which one has to move?). These sub-concepts are linked together thanks to the lexical relation of synonymy between their associated term agents. Thus, according to the statistical features, Levenshtein distance [35], term agents can estimate their dissimilarity with others. Then, one sub-concept agent sends a message called vote, to its parent agent Component, including the list of its brothers concept agents sorted by dissimilarity Full-size image (<1 K). The selected sub-concept agent Frame sends a request to establish (is-a) relation with the new concept agent Full-size image (<1 K). The latter accepts and notifies (Frame) Full-size image (<1 K). Therefore, the concept agent Frame moves to the created agent Full-size image (<1 K). The split operation generates a Non Cooperative Situation of inefficiency which is the election of a preferred concept label. The new concept agent has to be renamed with an appropriate label. To resolve this problem, the AMAS asks the ontologist for help by executing the operation of ≪ concept agent adaptation to renaming ≫.

Adaptation to grouping: When the ontologist proposes to group two concept agents, the AMAS creates a new concept agent as a parent concept agent for them. For example, the ontologist chooses the two concept agents (Window) and (Panel) for grouping. The AMAS reacts immediately by creating a new concept agent as a sub-concept of the concept parent of (Window) and (Panel). The relevance value of the created concept agent is the maximum one between the relevance values of (Component), (Window) and (Panel).

The concept agent (Panel) removes its relation with (Component) Full-size image (<1 K) (Fig. 10). Then, it establishes an (is-a) relation with the new concept agent Full-size image (<1 K). Simultaneously, (Panel) proposes the new parent concept agent to (Window) Full-size image (<1 K). Therefore, (Window) cancels its old relation with the concept agent (Component) and establishes an (is-a) relation with the new one Full-size image (<1 K).

The grouping operation generates a Non Cooperative Situation(NCS) of inefficiency which is the election of a preferred concept label. The new concept agent has to be renamed with an appropriate label. To resolve this problem, the AMAS asks the ontologist for help by executing the operation of renaming concept.

Adaptive concept agent relevance value: As mentioned above in the section of term agent relevance value, OntoAMAS has to learn how to automatically adjust the concept agent relevance value according to ontologist actions by implementing the adaptation mechanism using the following formula:

where P1 is the highest relevance value of its conceptual relations, P2 represents the quality of its concept agent neighbors (valid or not yet); P3 corresponds to the status of its conceptual relations (accepted or refused); P4 is the depth of the concept agent in the ontology (−1 if it is connected to the concept ≪ TOP ≫, otherwise 1); P5 indicates the quality of the term agents denoting the concept agent (relevant or not) and the different weights α1,α2,α3,α4,α5α1,α2,α3,α4,α5 are respectively fixed to 0.5, 1, 1, 1 and 2 [5].

Initially Stdegree = 2; the value of Coef varies according to the ontologist feedback:

—if the ontologist accepts the concept agent then

Algorithm 1.

General algorithm of the agent adaptive behavior

where ConceptAgRelevance is the current relevance value of the concerned concept Agent and Threshold is fixed to 5.

After 10 successive ontologist actions, OntoAMAS starts supervising his/her behavior.

—If the number of acceptance actions exceeds the number of rejection or removing actions, the ConceptAgRelevance has to be increased by adjusting the value of Stdegree, Stdegree = 3.

—If the number of rejection or removing actions exceeds the number of acceptance ones, the ConceptAgRelevance has to be decreased by adjusting the value of Stdegree, Stdegree = 1.

—Otherwise, Stdegree keeps its initial value, Stdegree = 2.

We present the general algorithm of the agent adaptive behavior in Algorithm 1.

4. Evaluation of OntoAMAS

In this section, we introduced some implementations and experiments to test the feasibility of our proposed approach in addition to an evaluation that validates our hypothesis that the AMAS performance (quality of OntoAMAS results) has been improved and that user time during evolution has indeed been decreased through the use of the GUI with comparable results to DYNAMO-MAS [4].

4.1. Implementation and experiments

We implemented OntoAMAS tool as a plug-in in Protégé ontology editor. OntoAMAS extends TextViz [33] another Protégé plug-in dedicated to documents semantic annotation. The behaviors of OntoAMAS agents have been developed with the platform Make Yourself Agents [36] (MAY: Eclipse plug-in). When the ontologist adds a new document (one or more) to the corpus, new candidate terms and new lexical relations are extracted by the corpus analyzer. When it sends them to the AMAS, the OntoAMAS is triggered; new term agents are created and possible local interactions with other agents occur in order to find their appropriate location in the organization Full-size image (<1 K) (Fig. 11). Most of the agents update their knowledge, communicate and react to finally reach a stable state. Therefore, a new draft of the ontology is proposed to the ontologist as a set of proposals in the GUI. All the concepts and the terms of the ontology are displayed in the Concepts Browser panel Full-size image (<1 K) and in the Terms Browser panel Full-size image (<1 K). The red-colored proposals represent the terms and concepts with a relevance value that exceeds the threshold of proposition. The ontologist expresses his/her reaction by applying elementary and composite changes via the GUI Full-size image (<1 K). Each ontologist's action raises a feedback to the AMAS and triggers it again. The added adaptation mechanism to the agents behaviors allows them to update their knowledge again and to recompute their relevance values. Therefore, an update of the proposals will take place and potentially leads to an update of the display. Finally, the ontology will be saved in an OWL format (a standard that makes it easily reusable). Only validated proposals by the ontologist will be saved in the OWL.

We start testing our tool by implementing the adaptive behaviors towards elementary changes. We have carried out OntoAMAS tests with two different ontologies and an associated corpora. Each ontology has been manually built and validated regarding to the corpus annotation. The ontology seeks to annotate its associated corpus that is accurate enough to support an efficient document retrieval. In these two domains, the corpus contains a reduced number of small size documents (a few paragraphs).

—Arkeotek ontology: a French ontology on archeology about traditional techniques, built with 380 concepts and 733 terms and associated to a corpus made up of 299 documents (rule-based formulation of scientific papers).

—Artal ontology: an English ontology on software bugs reports made up of 887 terms and 582 concepts; the corpus is composed of 287 documents (bug report files).

We considered two metrics to evaluate OntoAMAS:

1. Quality Evaluation: to prove the relevance of OntoAMAS suggestions: we checked if the ontologist considered them as valid.

2. Performance Evaluation to test the effectiveness of GUI design and its user-friendliness in minimizing the time spent to construct the final draft.

4.1.1. Quality evaluation

To evaluate the quality of OntoAMAS proposals, we firstly compared a manual and an automatic ontology evolution and then we made a comparison between our tool results and the ones of DYNAMO-MAS starting by reproducing the same experiment [5]. The manual evolution was performed by the ontologist who added new terms and new concepts to the ontology. The evolution is automatic if the ontologist uses our tool. In each domain, an ontologist has expressed his/her feedback towards the MAS proposals via the graphical interface (Fig. 11).

After the addition of 12 new documents to the corpus of Arkeotek, the ontology was enriched by the ontologist with the insertion of 7 new concepts and 19 new terms. Starting with the same ontology and the same new added documents, OntoAMAS proposed 27 new concepts (16 were accepted by the ontologist) and 32 new terms (22 were accepted by the ontologist). The details of this result are shown in Table 3. The first row of the table, the AMAS proposal, represents the sum of the rows 2, 3 and 4 (relevant, correct and wrong/useless/refused proposals). The accepted proposals are the result of the sum of the two table rows representing the relevant proposals (set at the right place in the ontology) and the correct ones (set at a wrong place in the ontology). The third row represents the wrong/useless/refused proposals and the last row represents the proposals suggested both by the ontologist and OntoAMAS.

With the Arkeotek dataset, OntoAMAS reached 68.75% of correct and relevant term proposals and 59.26% of correct and relevant concept proposals. When we compare the manual and the automatic evolution of the ontology, we note that, OntoAMAS suggested 18 terms and 14 concepts, that were not identified by the ontologist, to enrich the ontology. So the AMAS can be seen as an interesting tool to help an ontologist to accurately evolve his/her ontology.

After the addition of 21 new documents to the Artal corpus, the ontology was enriched by the ontologist with the insertion of 9 new concepts and 19 new terms. Starting with the same ontology and the same new added documents, OntoAMAS proposed 18 new concepts (10 were accepted by the ontologist) and 24 new terms (16 were accepted by the ontologist). Table 6 shows more details of these results.

With the Artal dataset, OntoAMAS reached 67% of correct and relevant term proposals and 56% of correct and relevant concept proposals. When we compare the manual and the automatic evolution of the ontology, it can be noted that, our tool suggested 12 terms and 9 concepts not proposed by the ontologist, to enrich the ontology.

As the process of the ontology evolution is iterative, we repeated the step of the ontologist intervention until a satisfactory and consistent ontology was obtained (the consistency is defined by the ontologist and the applications depending on the ontology). In each iteration we tested (i) the number of accepted terms and concepts proposed by OntoAMAS, (ii) the number of wrong, useless and refused ones and (iii) we compared the proposals generated by OntoAMAS to those suggested by the ontologist.

To confirm the reliability of the ontologist's role in improving the quality of OntoAMAS proposals, we tested our tool after two successive interventions of the ontologist. We presented in this evaluation only 3 iterations however the number of ontologist's interventions is not static and depends on the consistency of the ontology and the satisfaction of the ontologist. Table 4 and Table 5 show the following results:

The second iteration indicates that OntoAMAS attains, with Arkeotek ontology, 70% of accepted term proposals and 66.6% of accepted concept proposals. By exploiting the ontologist's feedback, the number of proposals generated by both the ontologist and OntoAMAS increased to 5 terms and 3 concepts. The third iteration reveals an improvement in the number of accepted term proposals to 73.33% and accepted concept suggestions to 69.23% and an increase in the number of similar terms and concepts made both by the ontologist and the OntoAMAS.

In the case of the Artal ontology, the second iteration in Table 7 shows that OntoAMAS reached 69% of accepted term proposals and 70% of accepted concept proposals. By exploiting the ontologist's feedback, the number of proposals generated by both the ontologist and the OntoAMAS increased to 5 terms and 2 concepts. The third iteration reveals an improvement in the number of correct and relevant term proposals to 75% and accepted concept suggestions to 71.5% and an increase in the number of similar terms and concepts made by both the ontologist and the OntoAMAS as shown in Table 8.

To evaluate the efficiency of OntoAMAS, the proposal results of DYNAMO-MAS and OntoAMAS were compared (see Table 9). After the addition of 12 new documents to the Arkeotek corpus, DYNAMO-MAS generated 68.75% of accepted term proposals and 59.26% of accepted concept proposals. However, the same test proved that OntoAMAS reached 73.3% of accepted term proposals and 69.23% of accepted concept proposals.

After the addition of 21 new documents to the Artal corpus, DYNAMO-MAS generated 67% of correct and relevant term proposals and 56% of correct and relevant concept proposals [5]. However, the same test proved that our OntoAMAS reached 75% of correct and relevant term proposals and 71.5% of correct and relevant concept proposals.

4.1.2. Performance evaluation

Besides the improvement of the quality of the results provided by the OntoAMAS, our second challenge was to reduce the time to obtain an evolved ontology. Indeed, The limitation of DYNAMO [3] and [6] and DYNAMO-MAS [5] and [24] stems from the lack of user-friendliness which ensures a reliable interaction with the system results. Even with a limited size of an ontology, the ontologist faces difficulties in following the several changes achieved autonomously in only a very short time (few seconds). On the other hand, a small intervention of the ontologist can potentially generate important impacts on the structure. Consequently, the ontologist spends a lot of time (around three hours [23]) to localize the involved concepts and terms and the new suggestions in the graph display. A great part of the time spent to evolve the final draft ontology is due to the difficult handling of the GUI. In DYNAMO-MAS, experiments [24] showed that the time taken to automatically evolve an ontology is longer than a manual maintenance. This is due to the response time during validation of a proposal using PROMPTDIFF tool. To deal with this problem, we resorted to an ergonomist to design an easy-to-use GUI (Fig. 11). Designing an optimal interface enhances the interaction time and makes it shorter. During the experiments we noticed the efficiency of our interface: it allows displaying the current ontology to the ontologist with red-colored new proposals which dynamically changes.

4.2. Analysis and discussions of results

To summarize, OntoAMAS is independent of the language and the domain of the handled texts. It runs an ontology evolution in two different domains and supports two languages (English and French). The obtained results are promising and confirm the efficiency to take into account the role of the ontologist's intervention in the improvement of the OntoAMAS suggestions. Thanks to the iterative and interactive aspect of the evolution process, after each successive iteration we noticed improvements in the quality of OntoAMAS proposals. In fact, the number of the wrong and useless proposals decreases and the number of relevant ones increases. This due to the following two reasons:

—The implementing of the adaptation mechanism with the formula that represents the agent relevance value: thanks to the parameter ≪ Strictness Degree ≫ (Stdegree) defined above in Section 3, OntoAMAS learns how to vary the relevance value of the agent according to the interactions with the ontologist. Subsequently after a given number of the ontologists actions, the OntoAMAS proposals will be updated by eliminating those that do not exceed the proposals threshold and by adding those that exceed it.

—The cooperative behaviors of the agents: as mentioned in Section 3, each agent has local knowledge about itself and its ≪ neighbor ≫ agents with whom it has already interacted. Each agent has a status (candidate or not) indicating whether the agent is actually part of the ontology(valid agent) or is at proposal stage (invalid agent). It behaves according to cooperative interaction rules. It updates its knowledge and recomputes its relevance value according to the updated parameters values.

When the ontologist makes his/her decision (accepts, rejects, modifies, etc.), the concerned agent will be notified and updates its status. For example if the ontologist accepts an agent to be a apart of the ontology, it updates its status to become a valid agent. Therefore, its neighborhood updates their knowledge and recalculates its relevance value which necessarily will be increased thanks to the parameter P2 representing the quality of its agent neighbors (valid or not yet). When the value of P2 contributes to increasing the agent relevance value above the threshold, then it proposes itself to be part of the ontology. However if the ontologist rejects a proposal, the parameter P2 decreases and therefore the relevance value decreases. P5 is another parameter in the formula which may affect the relevance value of the concept agent. P5 represents the proportion of relevant term agents that denote this concept agent. Thus, when the ontologist validates a term agent, P5 increases; else it decreases and consequently the relevance value of the concerned concept will be reduced and is likely disappear from the updated proposals list.

Moreover, we should note that the OntoAMAS converges and that the average of the number of the ontologist's interventions (actions towards the proposals of OntoAMAS) progressively decreases. After each successive iteration carried out by the OntoAMAS and the ontologist, the improvements in the quality of OntoAMAS proposals (the number of relevant proposals increases and the wrong and useless proposals decreases) facilitate the task of the ontologist and consequently reduce his/her frequent involvement.

5. Conclusion

The main goal of this paper was to propose OntoAMAS, an ontologist feedback tool based on an adaptive multi-agent system for an ontology evolution. OntoAMAS is an innovative tool from three points of view:

—From the point of view of ontology evolution, this work is a first step showing the relevance of the DYNAMO-MAS extension. The originality comes from the fact that OntoAMAS can be triggered when new document is added to the corpus at any time or when the ontologist makes some improvements in the proposed results. OntoAMAS and the ontologist modify the same ontology in a cooperative and adaptive way: this process relies heavily on the strong relation between the action of one of them and the reaction of the other. That is to say, thanks to the adaptation mechanisms added to the agents' behaviors, OntoAMAS exploits the ontologist's feedback (elementary and composite changes) and self-adapts to personalize its proposals.

—From the adaptive multi-agent modeling point of view, in our situation of self-organization, complexity and emergence through cooperative and adaptive interactions, AMAS (agentification and a number of heuristic rules) has been a relevant solution and proved its efficiency in the context of a dynamic ontology.

—From the point of view of time performance, designing and developing OntoAMAS graphical interface proved its efficiency when the time taken to ensure the interaction between the ontologist and the AMAS gets shorter.

We carried out some experiments of OntoAMAS to evaluate its performance and the quality of its suggestions by (i) implementing the adaptive behavior of the agents towards the elementary changes made by the ontologist and (ii) designing an user-friendly GUI. The obtained results are promising. The current state of our tool enables to decrease the number of the wrong and useless proposals and to increase the relevant ones. OntoAMAS proposes some of the terms and/or concepts that have been produced manually by the ontologist and also concepts and terms that have been forgotten by him.

From these improvements we mostly focused on enhancing the adaptation mechanisms. We are currently implementing the adaptive behavior of the term and the concept agents towards the composite changes (they possess richer semantics to express evolution [37]). We plan also to experiment the quality of OntoAMAS proposals with ontologies concerning different domains, expressed in different languages (French and English). In the validation step, If only one user participated in the evaluation, what if another one performed better? Cross-user agreement would be a great addition to this evaluation.

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Parametric As-built Model Generation of Complex Shapes from Point Clouds

Luigi Barazzetti [1, *]

[1] Politecnico di Milano, Department of Architecture, Built Environment and Construction Engineering, Via Ponzio 31, 20133 Milan, Italy
* Corresponding Author. E-mail: luigi.barazzetti@polimi.it

Abstract. This paper presents a novel semi-automated method for the generation of 3D parametric as-built models from point clouds. Laser scanning and photogrammetry have a primary role in the survey of existing facilities, especially for the generation of accurate and detailed as-built parametric models that reflect the true condition of a building. Various studies demonstrate that point clouds have a sporadic adoption in large and complex parametric modeling projects. The lack of advanced processing algorithms able to convert point clouds into parametric objects makes the generation of accurate as-built models a challenging task for irregular elements without predefined shape.

The proposed semi-automated method allows the creation of parametric models from photogrammetric and laser scanning point clouds. The method is intended as a multi-step process where NURBS curves and surfaces are used to reconstruct complex and irregular objects, without excessive simplification of the information encapsulated into huge point clouds to avoid heavy models useless for practical purposes and productive work. Different case studies derived from actual BIM-based projects are illustrated and discussed to demonstrate advantages and limitations of the method.

Keywords: As-built; Automation; Laser scanning; Parametrization; Photogrammetry; Point cloud.

1. Introduction

The generation of accurate as-built parametric models of objects surveyed with point clouds is a complex task of primary importance in reuse projects of existing buildings [41]. Laser scanning and photogrammetric point clouds provide a huge amount of metric information that reveals the actual shape. However, point clouds have to be turned into useful models for the different specialists (architects, engineers, restorers, etc.) involved in the project.

Direct geometric modeling is the process of creating static 3D models with both simple and complex surfaces. On the other hand, the use of Building Information Modeling is becoming more important for construction, renovation, reuse and management projects. Here, the static representation offered by direct geometric modeling is not sufficient. Parametric modeling can be intended as the process of "redrawing without redrawing". If (direct) geometric modeling aims at providing a static reconstruction of the objects, in parametric modeling distinct objects can be interactively modified by changing the numerical values in a set of predefined parameters stored in a database (Fig. 1).

According to Eastman et al. [16, Chapter 1], parametric objects (i) contain geometric information and associated data and rules, (ii) have non-redundant geometry, which allows for no inconsistencies, (iii) have parametric rules that automatically modify associated geometries when inserted into a building model or when changes are made to associated objects, (iv) can be defined at different levels of aggregation, and (v) have the ability to link to or receive, broadcast, or export sets of attributes such as structural materials, acoustic data, energy data, and cost, to other applications and models. Parametric modeling refers to a virtual construction with fully-defined objects that know where they belong, how they relate to other objects and what they consist of [43].

Automated reconstruction of indoor scenes from point clouds has a direct connection to parametric modeling. Nowadays, 3D indoor modeling in real construction projects is mainly a manual procedure, that is time consuming and labor intensive [27]. Automated algorithms assume that the scene is composed of several primitive such as planar parts and arbitrarily shaped clutters [32]. As mentioned, automated algorithms have a strong connection to as-built parametric modeling strategies for the need of planar shapes detected with robust data processing algorithms [11], i.e. automated procedures able to detect wall segments and remove outliers. Volumetric modeling approaches were also proposed by Oesau et al. [33] to deal with multi-level buildings with arbitrary wall directions.

In recent years, parametric modeling has gathered more attention for the increasing demand of Building Information Modeling (BIM) in construction projects worldwide [9] and [46]. BIM relies on a 3D model made of objects with a rich set of attributes stored in a database. Objects are defined as parametric objects with relationships to other parametric objects. The 3D model is not only a static representation of the facility, but also an advanced computer technology to manage information for the automatic generation of drawings (sections, plans, etc.) and reports, design analysis, schedule simulation, thermal and structural simulation, facilities management, and much more. Although as-designed BIM (i.e. BIM generated in the design phase of a facility) has reached a sufficient maturity for practical purposes, as-built BIM generation (i.e. BIM of existing facilities generated from a preliminary survey, see Fig. 1) is still a challenging task where it is difficult to capture, interpret and represent as-built conditions in a complete BIM workflow [6], [18] and [38]. As-built BIM refers to BIM of existing buildings where an as-designed BIM could be also available ("as-built" means "as-is"). In other words, it reflects the real conditions of the construction, which could be different than those reported in the as-designed BIM or existing drawings [42].

In the design stage of a facility, architectural, engineering and technical issues are analyzed in common workflow to arrive at the global definition of the construction process. Numerous researchers have explored the potential offered by integrated 3D modeling instead of a more traditional 2D design. The advantages of BIM technology can also be exploited for existing buildings [1] and [45]. The use of existing drawings (including CAD) to generate the as-built BIM can be a source of errors in the case of variation orders during the construction phase, which is a common problem in construction projects [23] and [31]. Only a detailed survey of existing buildings can reveal the actual shape of the structures, which can differ from the designed form because of local anomalies, degradations and damages.

Photogrammetry and laser scanning technology are rapid and accurate measurement techniques that can support the generation of as-built BIM. Both provide dense point clouds with millimeter level accuracy, revealing the real external shape of constructive elements. However, few commercial BIM packages can read and display point clouds (e.g. Autodesk Revit and AECOsim Building Designer) to facilitate the integration of point clouds and BIM objects. Some new plugins are able to improve the interactive (manual) creation of BIM objects of simple elements, such as regular walls and columns, as well as Mechanical Electrical Plumbing (MEP) elements (e.g. pipes and conduits).

Automatic as-build BIM generation refers to the creation of BIM objects from sets of raw point clouds registered in a common reference system [8] and [21], including information from existing reports, analysis on materials, destructive and non-destructive tests, infrared thermography, etc. Fully automatic as-built BIM generation is still in its infancy and as-built BIM are usually produced with manual measurements, making the whole process time-consuming and error-prone. According to Nagel et al. [30], automatic reconstruction of buildings has been a research issue over the last 25 years with little success to date. They point out that the main issues for a complete automation of the workflow are related to the definition of a target structure that covers all variations of building, the complexity of input data, ambiguities and errors in the data, and the reduction of the search space during interpretation [44]. It is not difficult to understand why fully automatic as-built BIM generation from point clouds is a complicated task. Although laser scanning and photogrammetry are very popular solutions in 3D modeling projects (see for example [5], [25], [7], [12], [17], [20], [13] and [22], most 3D modeling techniques available today in commercial and scientific software do not provide BIM models. Mesh surfaces generated from packages for point cloud editing (e.g. Geomagic Studio, Polyworks, 3DReshaper, etc.), image-based software (e.g. PhotoModeler, PhotoScan, 3D Zephyr, Pix4Dmapper, Smart3DCapture, etc.), and advanced 2D or 3D modeling environments

(AutoCAD, Rhinoceros, Maya, 3D Studio Max, etc.) are not BIM objects. The geometric fitting of static primitives (e.g. planes, cylinders, etc.) is also a pure geometric process that does not fulfil the basic requirements of BIM projects.

Different BIM software (e.g. Revit, ArchiCAD, AECOsim Building Designer, Tekla BIMsight, etc.) are available on the commercial market and allow users to manually generate as-designed and as-built BIM. Some examples of complete as-built models from point clouds obtained in Revit and ArchiCAD were proposed by Murphy et al. [28], Baik et al. [3], Fai and Rafeiro [19], Oreni et al. [34], Barazzetti et al. [4], Dore et al. [15], and Quattrini et al. [39].

Because existing object libraries were mainly designed for design purposes (i.e. new constructions), the challenges faced in this paper can be described by the following questions: how can we generate an accurate as-built parametric model of irregular elements? Can we take into consideration geometric anomalies with such irregular objects? Can we preserve the level of detail achievable with dense point clouds? The proposed solution is a semi-automated tool able to simplify the generation of a parametric objects that take into account the geometric complexity. The outcome of this research is a novel tool for parametric modeling (from point clouds) which was already used in productive work, reducing time-consuming operations in manual modeling so that costs can be potentially reduced.

2. The developed solution for parametrization of complex shapes

The implemented solution for parametric as-built object generation (from laser point clouds) is based on NURBS curves and surfaces created in a semi-automated way. The case study used to highlight the importance of separating structural elements is shown in Fig. 2. The complex umbrella vault is located in Castel Masegra (Sondrio, Italy). Ribs have a circular organization that can be reconstructed with manual measurements on the point cloud. This allows a geometric reconstruction that preserves the uniqueness of the structure in terms of both architectural and structural aspects. The proposed approach can be summarized as follows.

- the (human) operator manually extracts the discontinuity lines of constructive elements (Fig. 2b), which are densified with a manual, semi-automated or automated approach, obtaining a dense network of curves (Fig. 2b);
- network and point clouds are used to fit NURBS surfaces (Fig. 2c);
- parametric objects are created to produce an editable volumetric representation (Fig. 2d).

NURBS (Non-Uniform Rational B-Splines) are mathematical functions with a clear geometric representation. NURBS can be computed with numerically stable algorithms, obtaining real-time results [36]. NURBS tools are also available in commercial packages for direct geometric modeling. However, the models generated in these processing environments are not BIM objects, but only static models without parametric representation. On the contrary, BIM software have a lack of tools for managing complex shapes surveyed with laser point clouds. The identification and simplification of the logic of construction of different structural elements is fundamental to create parametric objects, that become a detailed representation of the real structure.

2.1. From point clouds to NURBS

The reconstruction begins after the acquisition and registration of a set of point clouds [2], which can be generated with laser scanning or photogrammetric techniques. Then, the (expert) user identifies the different structural objects and their discontinuity lines. This is mandatory in BIM projects where different structural elements must be separated to obtain an object-oriented reconstruction.

The approach for the generation of discontinuity lines is based on NURBS curves. A NURBS curve is a vector-valued piecewise rational polynomial function of the form:

NURBS curves can be used to reconstruct standard shapes (lines, circles, parabolas, etc.) or free-form profiles. Post-processing (manipulation) is feasible by means of different strategies like control point translation, change of weight values, knot insertion/removal/refinement, and degree elevation. For these reasons, NURBS are very efficient functions to initialize the interactive part of the reconstruction, which also requires an interpretation of the different structural elements of the building.

The discontinuity lines of the umbrella vault in Fig. 2 were generated by selecting the control points on the point cloud, obtaining a set of NURBS curves of degree 3. This preliminary network of curves provides the boundaries of the vault and follows the logic of construction (how the structural elements is built), which cannot be neglected in the case of object-based projects.

NURBS curves are then used to initialise the generation of NURBS surfaces, which are functions of degree (p, q) in the directions (u, v) defined as:

NURBS surfaces are very used in the CAD/CAM industry for the opportunity to model simple and complex shapes. Natural quadrics (plane, cylinder, cone, and sphere), general quadrics, extruded surfaces, ruled surfaces and surfaces of revolution are commonly used in design and reconstruction projects. The proposed approach relies on NURBS surfaces generated from a set of curves in space, which are used as geometric constraint for surface interpolation. Although NURBS surfaces can be fitted to an unorganized point cloud, the final representation is usually very poor for sharp elements with discontinuity lines. The use of a preliminary set of curves for the generation of the surface is a more robust choice to drive the creation of the surface [36].

After the extraction of the principal discontinuity lines, surfaces are generated with a fitting process of the point cloud based on additional constraints given by the curve network. Two methods are used in the proposed workflow. The first one allows a strong control of the surface, which is estimated with an elegant mathematical solution from a dense curve network where the curves in one direction cross all curves in the other direction (self-intersections between curves in the same directions are not allowed). In this case, the reconstruction of the surface surveyed with point clouds is carried out with the NURBS network [Ck(u),Cl(v)][Ck(u),Cl(v)], obtaining a final NURBS surface S(u,v)S(u,v)

which interpolates the profiles in space so that Ck(u)=S(u,vk)Ck(u)=S(u,vk)(0⩽k⩽K)(0⩽k⩽K) and

Cl(v)=S(ul,v)Cl(v)=S(ul,v)(0⩽l⩽L)(0⩽l⩽L). A Gordon surface [24] can be estimated to overcome

the curve-surface fitting problem that has an infinite number of solutions. This particular solution is based on the sum of three surfaces S(u,v)=S1(u,v)+S2(u,v)-T(u,v)S(u,v)=S1(u,v)+S2(u,v)-T(u,v), where View the MathML sourceS1(u,v)=Σl=0sCl(v) α l(u) and View the MathML sourceS2(u,v)= Σ k=0rCk(u) β k(v) contains all Cl(v)Cl(v) and Ck(u)Ck(u). The blending functions View the MathML source{ α l(u)}l=0s and View the MathML source{βk(v)}k=0r satisfy the constraints:

An alternative solution to the surface fitting problem is needed when the curve network does not satisfy the previous requirements (e.g. any of the curves in one direction of the network do not intersect all of the other curves). The proposed solution uses surface deformation techniques [26] and [10] to generate progressive modifications of a seed surface according to a given curve network. In the proposed methodology, surface geometry is progressively adjusted to transform a planar seed surface into a new 3D surface that follows point cloud and curves. The seed surface is a plane with a predefined number of sub-divisions (usually more than 400). Local modifications in the seed surface can be performed by modifying weights, control points, and knot vectors. The procedure is carried out by considering multiple modifications not limited to a single parameter. For instance, the modification of a single control point leads to an unnatural final shape, whereas altering a set of control points provides a more realistic and smooth surface [35]. The method exploits the properties of NURBS for which a manipulation of a part of the surface provides modifications only in a confined area, without altering the whole surface.

The advantages of this second strategy rely on a more automated procedure that takes into consideration generic curve networks. Few manual profiles are needed to run this second methodology, which however is less stable than the previous method based on Gordon surfaces. As mentioned, the number of internal subdivision of the seed plane must be set beforehand. The orientation in space of the subdivisions is another essential parameter, otherwise the internal subdivision of surfaces will not follow the dominant direction of real objects. Boundaries (also called edges) are also extremely important because they delineate the appearance of a freeform shape. They are used to fit the surface and to join multiple surfaces.

Shown in Fig. 2c is the final NURBS surface for the umbrella vault, that is made up of NURBS surfaces of 3rd degree with a variable number of internal subdivisions (23×23 or 33×33). Manual boundaries (the interactive measurements used to define the curve network) are used to trim the surfaces obtaining a regular surface without interruptions.

2.2. From NURBS surfaces to as-built parametric objects

The set of NURBS surfaces is a reconstruction of the external surface of the objects surveyed with point clouds, whereas BIM objects are solids with parametric geometry. One of the main issues in as-built BIM generation is the choice of the parameters which need parametrization, as well as the kind of parametrization required. The aim of this paragraph is to demonstrate that a complex NURBS surface can be the starting point for a parametrization that provides an editable solid.

In the case of the vault shown in Fig. 2, parametric modeling is used to create a customizable solution for parts that cannot be reached by standard surveying techniques. As the laser scanning point cloud of the vault captured only the intrados (the inner surface of the vault in Fig. 2), there is no geometric information about the thickness (T) of the vault (only the ceiling is visible from upstairs, therefore the extrados cannot be surveyed). T becomes a dynamic parameter and an initial assumption can be used to provide a preliminary reconstruction. Obviously, this initial choice requires some information about the logic of construction. In this case, after a review of the different data sources (mainly existing reports), the initial thickness T was set to 200 mm, which can be automatically modified without redrawing by using parametric modeling. This is a remarkable benefit of parametric modeling: initial assumptions can be edited by simple modifications of the numerical value stared in the project database. The geometric model is automatically modified to correctly represent the new configuration, which is based on the assumption that the extrados and the intermediate layers can be obtained by an offset of the intrados. Obviously, there is no guarantee that the thickness is constant and only a destructive inspection could reveal the real geometry. However, such hypothesis can be useful not only for the creation of a volumetric object, but also for other operations that require a solid representation, such as cost analysis and estimation of volumes. The generation of a multi-layer structure with multiple offsets is also mandatory to take into consideration the different materials of the vaults.

Given a NURBS surface $S(u,v)S(u,v)$, the offset surface is $S'(u,v)=S(u,v)+TN(u,v)S'(u,v)=S(u,v)+TN(u,v)$, where TT is the offset distance and N the normal vector. $S'(u,v)S'(u,v)$ is not only a translated copy of the original surface, but a different NURBS surface. A precise solution to the offset problem can be found only for a limited number of standard surfaces (e.g. cylinders and spheres), whereas generic NURBS representations require numerical approximations. In addition, the offset surface is usually made up of a larger number of control points and knots, which can be simplified to reach a predefined tolerance [37]. The computation of $S'(u,v)S'(u,v)$ can be carried out by surface sampling based on the second derivative, then the offset surface is simplified via knot removal. The sub-vertical edges of offset and original surfaces are then connected with other NURBS surfaces to obtain a volumetric representation.

Fig. 3 shows the result for the umbrella vault. As mentioned, BIM objects require a volumetric representation where the reconstruction must be completed by additional NURBS surfaces that interpolate the volume between intrados and extrados. The thickness T was the unique parametrized value used to generate different volumetric representations of the vault. The different parts of the vault surveyed with point clouds (e.g. the intrados) were instead considered static shapes.

Parametric modeling can be used for several purposes. The reconstruction of the vault shown in Fig. 2 and Fig. 3 demonstrate that parametric modeling can be used to create a customizable solution for parts that cannot be reached with standard surveying techniques. This aspect introduces a relevant problem about the choice of elements that require parametrization as well as the kind of parametrization required.

In the case of as-designed BIM projects, the parametrization problem concerns the size of the model (memory occupation) and the position and attitude of the object in space. For example, a door requires some positional parameters such as level (ground floor, basement, etc.), still height, and distances from the vertical edges of the walls. Geometric parameters are instead thicknesses, height, width, trim projection (exterior and interior), and trim width. In the case of the vault of Fig. 3, position and shape of the intrados are provided by laser scanning point clouds. After measuring the intrados of the vaults and representing the shape with NURBS surfaces, it was decided to create a parametric representation of the thickness. This is motivated not only by the complexity of the parametrization of the intrados, but also by the requirements of the project related to the preservation of the physical integrity of objects of historical value.

As-built parametric modeling has positional constraints that depend on metric data (point clouds in this case). However, the parametrization problem is quite generic (without guidelines or standards) and depends on two aspects:

1.the possibility to parametrize complex surfaces captured by point clouds (technology driven);

2.human interpretation and personal choices during the creation of the as-built model.

Different operators can make different decisions about the objects which need a parametric representation. This aspect is a relevant problem not only for as-built projects, but also in as-designed projects with predefined object libraries combined to complex shapes. Some examples are illustrated in Fig. 4, where complex surfaces generated with the proposed NURBS-based methodology were employed to obtain advanced "roof", "wall" and "curtain wall" objects. The shape of these irregular objects is not available in existing libraries and the creation of an "initial surface" turned into a parametric object is mandatory.

Although commercial BIM packages have native tools for NURBS modeling, only simple algorithms are available, mainly based for operations such as extrusion, blend, sweep, and revolve of splines. The use of these packages is not user-friendly and most designers prefer to work with other pure (direct) modeling environments such as Maya, 3D Studio Max, and Rhinoceros, which are more flexible but do not provide parametric objects.

The proposed solution for a parametric representation of the surveyed surfaces can be used for advanced as-designed BIM, as illustrated in Fig. 4. The surface of the roof (Fig. 4 – top) was generated through a loft starting from a set of NURBS curves, obtaining the base surface for the bottom part of the roof. An automatic offset was used to generate the top face, exploiting the advantages of parametric modeling. The object is correctly recognized as "roof" by Autodesk Revit, meaning that the relationships between the new roof and other elements can be used in an efficient and organized BIM project. Examples of BIM functionalities are the automatic connection between "roof" and "wall" and the "opening cut" for a chimney, both correctly recognized as advanced operations in the final BIM environment.

The basic surface of the wall in Fig. 4 (middle) is instead made up of a single NURBS surface of degree 2. Elements are not vertical because the NURBS curves (top and bottom) are different. In all, 30 (horizontal) × 18 (vertical) divisions were used to obtain the wall. The surface was turned into a generic "wall" object with a parametrization of the thickness, assuming the NURBS surface as the external part of the model. The new "wall" object is consistent with other predefined objects such as "windows" and "doors", that can be automatically placed inside the wall with a cut performed by the BIM software.

The last case (Fig. 4 – bottom) is instead a surface derived from planar NURBS curves placed at different heights. The surface was turned into a "curtain system" with glazed panels. An additional grid of 800 mm × 1000 mm was added to accommodate a rectangular "mullion". This operation is carried out in a fully automated way after setting the grid size as "the maximum space".

As can be seen, all objects have a particular parametric representation as well as semantic relationships with other objects [14]. Objects must have proper semantic components (beyond geometry) to provide an efficient and consistent project workflow, where geometry and relationships are therefore correlated by topological algebra. However, the case of complex shapes can provide additional issues. As mentioned in the previous sections, thickness parametrization can be obtained by an offset of the surface, which is not a simple translation along prefixed directions. Shown in Fig. 5 (top) is a detail of the roof illustrated in Fig. 4. The roof was modeled with an offset profile (orange). The offset is applied along the orthogonal direction to the surface in order to ensure a constant thickness. Then, the figure shows some additional offsets of the same distance. It is clear that the offset surface is not only a translated copy: it is a new function that can have geometric discontinuities.

Additional issues arise when the analysis is carried out by considering the whole surface and not only a line. As the original surface is generated from a set of irregular curves, offset curves are not constant. The problem is intended as the offset of the whole NURBS surface, which can lead to the geometric inconsistency shown in Fig. 5 (bottom). Self-intersections and other geometric issues are not only a visual problem that can be hidden with the closure of external surfaces. They are not compatible with basic parametric modeling requirements and can be revealed by BIM packages with procedures for clash detection (also called conflict checking). In the case of complex shapes, the aspect of self-intersection is still not completely solved in the proposed methodology. It requires future work to obtain consistent parametric representations for very complex shapes.

3. Testing in real as-built parametric modeling projects

The case studies illustrated and discussed in the paper are real applications where an accurate as-built parametric model was generated from point clouds. The case studies demonstrate that the proposed approach can provide accurate and detailed parametric reconstructions for specific constructive elements of irregular buildings. However, a particular attention is needed to understand the kind of parametrization required.

3.1. Case study 1: as-built parametric modeling in the case of geometric anomalies

Parametric modeling is not limited to buildings. It can be used for a large variety of civil infrastructures such as dams, bridges, tunnels or highways. Shown in Fig. 6 is the smokestack at Politecnico di Milano (Milan, Italy), which was surveyed with laser scanning technology. Eight scans were acquired with a Faro Focus 3D and were registered in a reference system given by total station measurements (the instrument used is a Leica TS30). The aim of the project was the generation of an accurate as-built model that takes into consideration the real shape of the structure. In particular, one of the goals was the inspection of verticality deflections and their accurate geometric representation.

Because the survey captured the external surface of the smokestack, one of the elements that required parametrization was the thickness of external walls along with the thickness of the piezometric water tower. The extraction of a NURBS curve network was carried with a set of horizontal and vertical cutting planes. The analysis of the horizontal sections provided information about the shape, which seemed circular above the reinforced concrete water tank.

As mentioned, NURBS curves can reconstruct free-form shapes as well as basic forms commonly used in technical drawings. The particular case of circles is considered here. Although the implicit equation f(x,y)=0f(x,y)=0 of a generic curve is unique up to a multiplicative constant, its parametric representation can be written in different ways. As the case study refers to circles, let us consider the circle of unary radius centered at the origin, whose equation is f(x,y)=x2+y2-1=0f(x,y)=x2+y2-1=0. Two distinct parametric forms can be written as:

This means that different ways to represent the same circle can be used. Graphical results for the previous circles are shown in Fig. 7. One may ask why a generic NURBS curve is not directly used for horizontal sections. The answer depends on several issues: constructions are gradually assembled following particular geometries and criteria. If the section is a circle, additional information is useful to plan further activities, i.e. geometric deviations from the initial hypothesis can be highlighted by point clouds and communicated to the different experts involved in the project. In addition, if sections can be described by circles, geometric operations for thickness parametrization can be rigorously carried without approximations (circles can be offset precisely).

A set of equally spaced horizontal sections was extracted for the part above the water tower. After least squares circle fitting the statistics for the different sections were analyzed. The precision σaσa, σbσb, σrσr of center coordinates (a,b)(a,b) and radius rr were computed for the fitted circles, obtaining good geometric correspondence for the lowest levels (section 1, 2, 3, 4 with precision better than ±2 mm). A progressive worsening of fitting results was found on top of the smokestack (section 5 with precision of about ±4 mm). This confirms the initial hypothesis about the circular sections of the structure. A progressive deviation from verticality was discovered for the computed center coordinates (a,b)(a,b) at different levels. The horizontal deviation is larger than 100 mm on the top of the structure. This is a very important aspect that must be taken into consideration in the final model.

The creation of the as-built model was carried out by using generic NURBS of 2nd degree for the circular shaft, adding vertical sections that follow the longitudinal direction of the structure. The pillars of the water tower were modeled with NURBS of 1st degree, whereas horizontal circles and (vertical) NURBS curves were used for the water tank. Metal stairs were simply included as static shapes without parametrization (direct modeling). A visualization of the final model and some details are shown in Fig. 8.

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3.2. Case study 2: preservation of accuracy in as-built models from point clouds

As-designed models can be delivered with a scale factor 1:1 to satisfy the requirements of typical projects with variable metric scales and levels of detail. The scale factor (mm) achievable from a survey depends on the size of the object, the instruments for data acquisition and the procedures used to turn raw data into usable products. Given a separation threshold e = 0.2 mm in printed project boards (usually used in cartographic and mapping applications), the corresponding metric value in terms of world coordinates is given by E=e·mE=e·m. A laser scanner with a precision of ±2 mm can be used to obtain a representation with scale factor 1:10 (i.e., E = 2 mm), that is more than sufficient for common project scales 1:20, 1:50, and 1:100. On the other, this is not sufficient to reach the scale 1:1 of as-designed objects (i.e., E = 0.2 mm).

As demonstrated in the previous section, existing constructions have deviations (vertical deflection, variable thickness, etc.) from the basic assumptions made in the design phase. These deviations should be taken into consideration during the creation of the as-built model (according to the needed level of detail and metric scale). The previous statement plays a fundamental role in a cost-effective approach for productive work. The creation of the as-built model comes at a cost and a correct estimation of time and cost needed to complete the survey is crucial [40].

The proposed methodology for parametric modeling can be assumed as a scalable procedure where parameters are interactively handled to preserve the metric information encapsulated into laser clouds. This aspect should be taken into account to reduce the size of the final model, avoiding useless details and enhancing productivity. For instance, coarse reconstruction scales (1:100–1:200) do not require fine details, which can result in time and cost issues as well as heavy models in terms of memory occupation (data storage).

Given a set of registered point clouds, a variable level of detail of the NURBS-based reconstruction approach can be exploited following an automated strategy which ends when the expected metric accuracy has been reached. Shown in Figs. 9 and 10 are the results for the mosaic of the chapel of San Vittore in Ciel d'oro in the Basilica of Sant'Ambrogio (Milan, Italy). The short distance (less than 4 m) between the laser scanner and the dome (during scan acquisition) provided a point cloud with an expected accuracy of ±2–3 mm.

Modeling was initially carried out by fitting a sphere through the measured laser scanning points. As NURBS surfaces can model both natural and general quadrics, it is simple to use a sphere for the first approximation. Geometric parameters were estimated via least squares. Then, the sphere was compared to the raw point cloud with the commercial package Geomagic Studio. The estimated standard deviation of the overall discrepancy was ±25 mm, much larger than laser precision, but still sufficient for coarse project scales (i.e. 1:100 or 1:200).

Data processing was then repeated with a progressive densification of NURBS curves, which form a consistent network in space (Fig. 10). A multi-resolution approach was used for the network with 3, 10, 20, and 33 internal subdivisions. An increment of the subdivision provided a more flexible solution, leading to a progressive improvement of geometric accuracy. As the whole procedure is fully automated and provide real-time results, the user can set a small initial number of divisions and check the quality of results in terms of discrepancy with the point cloud. The procedure can be iterated by increasing the number of subdivisions until the expected accuracy is reached. In this case, the expected accuracy of raw data was found with 33 × 33 subdivisions, for which the global discrepancy of 2.1 mm was similar to the precision of the laser scanner.

The surface was then converted into a parametric object with the automated offset of the thickness. Results are shown in Fig. 10, where additional images can be projected on the final NURBS surface by using texture mapping algorithm. The thickness has an internal layer-based structure that can be handled by expert operators interested in conservation.

4. Parametric modeling of historic buildings

Additional information is always needed in the case of historic buildings. Because they are the result of progressive transformations, existing drawings, reports, and a historic research cannot be neglected to understand and clarify the complexity of the building.

The generation of the parametric model can be carried out from a combined analysis of the collected data. Simple and regular objects can be directly modeled with commercial BIM packages available on the commercial market (Autodesk Revit in the proposed case study), whereas complex shapes can be reconstructed with the proposed procedure. Finally, complex objects are imported in a common processing environment to allow the different specialists involved in the project to exploit the final parametric model.

An example of historic building (surveyed with laser scanning techniques and photogrammetry) is shown in Fig. 12. The building is the "loggia" of Castel Masegra (Sondrio, Italy) where a geodetic network was used for scan registration, obtaining a precision better than ±3 mm. The as-built parametric model of the building was generated from laser scanning point clouds integrated with an accurate visual inspection of constructive elements and their materials, as well as infrared thermography, information from destructive testing (coring, flat jack tests), historical research, and existing drawings. Multiple data sources were fundamental to obtain an exhaustive description of the building, revealing some interesting aspects which were correctly included in the final model.

For instance, some vertical and horizontal profiles extracted from the laser cloud revealed a lack of correspondence between the external walls of basement and ground floor. This is also confirmed by the historical research, from which it was evident that basement and ground floor belong to different construction stages. Another interesting aspect is the variable thickness of external walls (North wall ≈ 1 m, South wall ≈ 0.60 – 0.70 m, East wall ≈ 0.60 – 0.65 m, West wall ≈ 0.60 – 0.70 m, internal walls = 0.90 – 0.95 m), which corresponds to the modifications occurred in the past (construction and demolition). External walls are not orthogonal and have a residual rotation of about 9° for the South facade, 3° for the East facade, and 2° for the West facade. The inspection of vertical laser sections revealed a variable thickness for the different floors and some deviations from the vertical direction.

One of the aims of the project was the creation of an interoperable model that can be managed by commercial software. Autodesk Revit was chosen as final processing environment and was sufficient for the reconstruction of simple and regular elements that can be correctly represented by predefined libraries, or a set of new libraries generated in Revit. Data processing with NURBS curves and surfaces was mandatory for complex elements like vaults and arches, which were directly modeled with a parametrization of NURBS surfaces. A preliminary attempt with the basic functions of Revit was carried out to model complex objects with geometric anomalies. On the other hand, Revit was not sufficient for the representation of the geometric anomalies previously described, which required NURBS curves and surfaces turned into parametric objects.

Examples of objects directly modeled with existing Revit libraries are beams and trusses. In this case, the required level of detail (scale 1:50) and the analysis of the shape with the point cloud revealed that standard libraries were sufficient (Fig. 13). Other elements directly reconstructed in Revit were floors and ceilings, which seemed quite regular after the inspection of laser scans.

The reconstruction of the columns was instead impossible with the sets of existing libraries. A new ad-hoc library was created by using NURBS curves to produce surfaces with a complete geometric parametrization. Their modeling was directly carried out in the family editor of the software and processing algorithms such as revolution and extrusion. The new object "column" is subdivided into 4 parametric objects with an edge-to-edge constraint and a complete three-dimensional parametric representation of different parts. An additional constraint based on "middle points" was included to provide a symmetric reconstruction (Fig. 14).

The reconstruction of the roof needed a combined approach. As mentioned, some parts were modeled with standard Revit families (e.g. beams and trusses), whereas the shape of roof external layer is very irregular and was modeled with the strategy based on NURBS curves and surfaces (Fig. 15). The six complex vaults were modeled only with the proposed NURBS-based solution. Indeed, 3D modeling tools available in Revit (including existing libraries and new families generated with the editor tool) were not sufficient for an accurate geometric representation of the irregular vaults. For this reason, the vaults with lunettes were modeled with the extraction of their breaklines from the point cloud. Then, curves were used as external constraint to drive the generation of NURBS surfaces. The same procedure was repeated for the barrel vault, that is quite irregular and required NURBS surfaces fitted with the proposed methodology (Fig. 15). Finally, the parametrization was included by generating a multi-layer offset surface for the reconstruction of the extrados, obtaining a complete solid objects.

The final as-built parametric model is made up of the following elements: 248 walls, 15 columns, 13 floors, 1 ceiling, 2 railings, 6 roofs, 8 stairs, 128 structural framings, and 2 "topographic" objects for the ground. Different parametrization levels were used for different objects, including a partial or full parametrization depending on specific functional requirements.

5. Conclusions

This paper presented a methodology for the generation of as-built parametric models from dense point clouds able to reveal the actual shape of existing constructions. Starting from a set of registered point clouds, NURBS curves that form a rigid curve network were extracted in a semi-automated way by considering the logic of construction of the building. Then, NURBS surfaces driven by both network and point cloud were generated to reconstruct the shape of complex objects along with their geometric anomalies. As NURBS are mathematical functions defined by numerical coefficients, a rigorous mathematical parametrization becomes feasible and allows the creation of parametric objects. The kind of parametrization shown in this work is optimal for constructive elements that require thickness parametrization with multiple layers.

The choice of NURBS curves and surfaces was motivated by the need to model complex and irregular geometries through numerically stable and fast processing algorithms. On the other hand, semi-automated measurements were mandatory for the lack of automated object-recognition algorithms able to recognize and separate the different constructive elements. Future research work will be carried out to improve the proposed methodology, especially the selection of parameters for surface fitting. Iterative algorithms that provides multiple solutions through the variation of predefined parameters can be implemented to arrive at a final surface that approximates the point cloud with a sufficient metric accuracy. Models with a limited number of subdivisions can be progressively refined to reach a compromise between the level of detail and the size of the model in terms of number of elements (e.g. NURBS surface subdivision). The numerical evaluation of the achieved accuracy can be estimated with a comparison with the point cloud. Particular attention will also be paid to self-intersection issues during the automated parametrization of complex shapes. The offset of complex objects made up of several surfaces can generate local problems (e.g. intersections) not consistent with the basic requirement of parametric reconstructions.

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Does Learning about Race Prevent Substance Abuse? Racial Discrimination, Racial Socialization and Substance Use among African Americans

Azure B. Thompson [1,*], Melody S. Goodman [2], Naa Oyo A. Kwate [3]

[1] National Center on Addiction and Substance Abuse at Columbia University, 633 3rd Ave, New York, NY 10017, United States
[2] Division of Public Health Sciences, Department of Surgery, Washington University in St. Louis School of Medicine, 660 S. Euclid Avenue, Campus Box 8100, St. Louis, MO 63110, United States
[3] Rutgers, the State University of New Jersey, 55 Dudley Rd, Cook Office Building, New Brunswick, NJ 08901-8520, United States
* Corresponding Author. E-mail: athompson@casacolumbia.org

Abstract. *Highlights* •On average, respondents reported experiencing racial discrimination in four settings.•Experiencing racial discrimination increased the risk of weekend and problematic alcohol use.•Moderation effects of racial socialization on these increased risks were tested.•Increased risks of weekend and problematic alcohol use were not moderated by racial socialization.

Keywords: Health disparities; African American/Black; Substance use; Tobacco use; Alcohol use; Racial discrimination.

1. Introduction

Substance use is the leading cause of preventable morbidity and mortality in United States. Tobacco and alcohol use in particular accounts for nearly 520,000 deaths annually, or an estimated one in five deaths per year (Mokdad, Marks, Stroup, & Gerberding, 2004). African Americans bear a disproportionate burden of tobacco and alcohol-related problems. African Americans are less likely than Whites to ever use tobacco and alcohol. However, once African Americans start using tobacco and alcohol, they are less likely than Whites to quit cigarette smoking(King, G, et al., 2004 and Thompson, AB, et al., 2011) and more likely to use alcohol and cigarettes at older ages,(Pampel, F., 2008, Keyes, KM, et al., 2015, Kandel, D, et al., 2011 and Geronimus, AT, et al., 1993) to develop alcohol abuse and dependence,(Grant, JD, et al., 2012 and Watt, TT, 2008) and to develop alcohol and tobacco related diseases such as cancer (USDHHS, 1998a).

Racial discrimination is a salient and pervasive experience in the lives of African Americans (Pager, D and Shepherd, H, 2008 and Feagin, J and Bennefield, Z, 2014) and is associated with substance use (Bennett, GG, et al., 2005, Borrell, LN, et al., 2007, Borrell, LN, et al., 2010, Clark, TT, 2014, Landrine, H and Klonoff, EA, 2000, Purnell, JQ, et al., 2012, Boynton, MH, et al., 2014, Kwate, NOA, et al., 2003, Gibbons, FX, et al., 2010 and Latzman, RD, et al., 2013). Racial discrimination is the exclusion of persons on the basis of race and one way dominant racial groups maintain racial hierarchies and privilege (Feagin & Bennefield, 2014). African Americans report racial discrimination in a number of settings including school, work and getting service in stores or restaurants (Pager & Shepherd, 2008). Experiencing racial discrimination can be an uncontrollable and unpredictable stressor, a type of stressor particularly harmful to health (Pascoe & Richman, 2009). Moreover, individuals who face racial discrimination in numerous settings report more fear and anger in anticipation of having to respond to it (Krieger, N., 2016 and Krieger, N, et al., 2005).

For some African Americans, substance use is a coping strategy to relieve stress from experiences of racial discrimination (Gerrard, M, et al., 2012 and Gibbons, FX, et al., 2010), as exemplified by studies that have found an association between those who report experiencing racial discrimination and lifetime (Clark, TT, 2014 and Purnell, JQ, et al., 2012) and current (Bennett, GG, et al., 2005, Borrell, LN, et al., 2007, Borrell, LN, et al., 2010, Clark, TT, 2014, Landrine, H and Klonoff, EA, 2000 and Purnell, JQ, et al., 2012) tobacco and alcohol use, and severity in use such as drinks consumed per day Kwate et al., 2003 and problematic levels of drinking (Boynton, MH, et al., 2014, Gibbons, FX, et al., 2010 and Latzman, RD, et al., 2013). However, African Americans learn to cope with racial discrimination in a number of ways (Greer, TM, 2011 and Pascoe, EA and Richman, LS, 2009). One way is racial socialization, the process by which individuals are taught values and beliefs pertaining to their racial group membership (Lesane-Brown, 2006). Racial socialization can include messages on how individuals should interpret and cope with experiences of racial discrimination (Brown, TN and Lesane-Brown, CL, 2006, Lesane-Brown, CL, 2006 and Neblett, EW, et al., 2010). Socialization processes usually occur during early stages of development (i.e., childhood and adolescence) but yield schemas on how to participate in social life that can last throughout the life course (Ardelt, 2000). Racial socialization experiences are generally associated with less negative affect once a racially discriminatory event has occurred (Bynum, MS, et al., 2007 and Lesane-Brown, CL, 2006).

No empirical study to our knowledge has examined the relationship between racial discrimination, racial socialization and behaviors related to substance use. Moreover, few studies examine the effects of early racial socialization processes on substance use later in life. We do so by examining associations between the number of settings in which racial discrimination is experienced and behaviors related to tobacco and alcohol use; and assessing whether racial socialization in early stages of development moderates these relationships. We hypothesized that the relationship between number of settings in which racial discrimination is experienced and behaviors related to tobacco and alcohol use depends on early racial socialization experiences, such that the relationship is stronger among African Americans who experienced racial socialization at low a frequency and weaker among African Americans who experienced racial socialization at a high frequency.

2. Materials and methods

The Black LIFE (Linking Inequality, Feelings, and the Environment) Study took place in two predominantly Black neighborhoods in New York City, the most populous city in the United States, with 8,175,133 residents. The residents of Brooklyn's Bedford-Stuyvesant and Manhattan's Central Harlem have moderate incomes: approximate median household incomes from the 2010 to 2012 American Community Survey 3-year estimates were $36,535 and $36,112, respectively (EpiQuery: NYC Interactive Health Data, 2012). Participants completed a baseline, 2-month follow-up and 1-year follow-up computer-assisted face-to-face interview. Data for baseline and follow-ups were collected between December 2011 and June 2013. The present analysis is based on baseline data.

2.1. Sample

Recruited were 144 participants from a probability sample of Black residents in the two neighborhoods. Randomly selected households were screened for adults eligible to participate in the study and then one household member was randomly selected for participation. Eligible adults were at least 18 years old, spoke English, self-identified as Black-African American, and had lived in the United States since at least 5 years of age. We excluded those who did not spend their formative years in the United States because experiences with racism are often different for individuals who grew up outside the United States (Kwate & Goodman, 2015). Overall response rates to initial recruitment across the 2 neighborhoods were 30% to 35%, reflecting difficulty in making household contact for screening; rates for successfully interviewing people were about 60% for eligible households. The sample was 52% female, with a mean age of 44.6 years.

2.2. Measures

2.2.1. Independent variables

We assessed the number of settings in which racial discrimination occurred with the Experiences of Discrimination (EOD) scale (Krieger et al., 2005). The EOD scale asks about ever experiencing discrimination attributable to race or ethnicity in the following 9 settings (e.g., at school, getting hired or getting a job, at work, getting housing, getting medical care, getting service in a store or a restaurant, getting credit, bank loans or a mortgage, on the street or in a public setting, from the police or in the courts). The EOD scale yields a numerical count of settings in which participants report having experienced racial discrimination.

Racial socialization was assessed using the Childhood Racial Socialization Experiences (RSE) scale, (White-Johnson, Ford, & Sellers, 2010) which asks participants to state how frequently (1 = never to 5 = always) racial socialization messages were received from parents, peers, and other adults during childhood and adolescence. Higher average scores indicate a higher frequency of racial socialization messages in childhood and adolescence.

2.2.2. Dependent variables

Tobacco use behaviors were being a lifetime and current cigarette smoker. Those who reported yes to “Have you ever smoked 100 cigarettes in your lifetime?” were classified as lifetime cigarette smokers. Current cigarette smokers were those who reported having smoked 100 cigarettes in their lifetime and were currently smoking every day or some days.

Alcohol use behaviors were weekday, weekend and problem alcohol use. To account for differences in temporal patterns of alcohol consumption, we assessed alcohol use during the weekday (Monday through Thursday) and weekend (Friday through Sunday). Alcohol consumption in the United States is higher during the weekend than the weekday (Arfken, 1988). Participants reported about how many drinks usually had during the weekend and weekday over the past month and were categorized into nondrinkers, moderate drinkers and heavy drinkers by day of the week. Women who averaged up to 1 drink per day and men who averaged up to 2 drinks per day were classified as moderate drinkers; participants who averaged more than moderate drinking levels were classified as heavy drinkers. Dietary Guidelines for Americans informed these alcohol use classifications (http://123.233.119.36:80/rwt/119/http/NBTXC5DVNAYGP55X/dietaryguidelines/dga2005/document/html/chapter9.htm, 2015).

We assessed problem alcohol use using CAGE. The CAGE–a mnemonic for attempts to cut back (C) on drinking, being annoyed (A) at criticisms about drinking, feeling guilty (G) about drinking, and using alcohol as an eye (E) opener—is a four item scale with each item scored 0 or 1. Answering affirmatively to two or more of these items suggests problem alcohol use (Ewing, 1984).

2.2.3. Covariates

We also included sociodemographic variables shown to be associated with alcohol and tobacco use such as age, gender, years of education, employment status and financial strain (Chartier, K and Caetano, R, 2010, Fellner, J., 2009, Grant, JD, et al., 2012, Godette, DC, et al., 2011, Keyes, KM, et al., 2015, USDHHS,, 1998b, Vogt Yuan, AS, 2011 and Watt, TT, 2008). Financial strain was assessed by asking participants how comfortably their household lived on the reported income; response choices were “always have enough money for the things you need,” “sometimes don't have enough money,” and “often don't have enough money.”

2.3. Statistical analysis

Analysis were weighted to account for nonresponse and to make post-stratification adjustments on age and gender. Regression analyses for survey data with complex sampling design and weighting were conducted with STATA version 13.1. Predictors of primary interest were the count of settings in which participants report having experienced racial discrimination and frequency of racial socialization experiences (RSE) during childhood and adolescence across sources (i.e., parents, family, and community) and control variables were age, gender, education, unemployment and financial strain.

First, we used weighted regression models to test whether there was an association between number of settings in which participants report ever having experienced racial discrimination and behaviors related to cigarette and alcohol use (Model 1).

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We then used weighted regression models to test whether the relationship between number of settings ever having experienced racial discrimination and behaviors related to cigarette and alcohol use was moderated by the frequency of racial socialization by including a racial discrimination × racial socialization interaction term (Model 2).

3. Results

As shown in Table 1, half (50%) of study participants were lifetime and one-quarter (25.4%) current cigarette smokers. Forty-two percent (42.0%) of study participants were moderate or heavy drinkers on the weekday and more than half (53.9%) moderate or heavy drinkers on the weekend. Nearly one in seven (15.2%) study participants met the criteria for problem alcohol use (Table 1).

On average, participants reported (SD = 0.23) experiencing racial discrimination in four settings. Participants most frequently reported discrimination while getting service in a store or restaurant (69%), on the street or in public settings (63%), getting hired or getting a job (57%) and from the police or in the courts (57%). Participants reported racial socialization experiences in childhood and adolescence ranging from 1 (never) to 5 (always), with an average of 2.8 (SD = 0.97) (Table 1).

Years of education ranged from 3 to 23, with a mean of 13.5 (SD = 3). Nearly half (46%) of the sample were unemployed and a majority (71%) reported sometimes or often not having enough money for the things they need (Table 1).

Correlations for the study variables are presented in Table 2. Being a lifetime cigarette smoker was significantly correlated with age and years of education; current cigarette smoker with years of education and being unemployed; weekend alcohol use with number of settings in which racial discrimination was experienced, frequency of racial socialization experiences in childhood and adolescence, age and being unemployed; and problem alcohol use with number settings in which racial discrimination was experienced.

Experiences of Racial Discrimination Scale (EOD): number of settings in which racial discrimination is experienced. Racial socialization experiences (RSE): frequency (1 = never to 5 = always) of racial socialization messages received from parents, peers, and other adults during childhood and adolescence.

Findings were considered statistically significant if p values were < 0.05. Table 3 presents findings from logistic regression models of tobacco use behaviors. The number of settings in which participants reported having experienced racial discrimination had no statistically significant effect on being a lifetime smoker (Table 3a, Model 1). In our moderation model, the number of settings participants reported having experienced racial discrimination had no statistically significant effect on being a lifetime smoker or interaction with racial socialization, such that the relationship between racial discrimination and lifetime smoking was not dependent on the frequency of racial socialization (Table 3a, Model 2). No statistically significant relationship existed between the number of settings in which participants reported having experienced racial discrimination and being a current smoker (Table 3b, Model 1). In our moderation model, the number of settings participants reported having experienced racial discrimination had no statistically significant effect on current smoking or interaction with racial socialization, such that the relationship between racial discrimination and current cigarette smoking was no dependent on frequency of racial socialization (Table 3b, Model 2).

We combined heavy and moderate drinkers into one category due to insufficient sample size of heavy drinkers. Therefore, logistic regression models were used to test our alcohol-related study hypotheses with nondrinkers as the comparison group. Table 4 presents findings from logistic regression models of weekday, weekend and problematic alcohol use. The number of settings in which participants reported having experienced racial discrimination had no statistically significant effect on being a moderate/heavy drinker (Table 4a, Model 1). In our moderation model, the number of settings participants reported having experienced racial discrimination had no statistically significant effect on being a moderate/heavy drinker or interaction with racial socialization (Table 4a, Model 2). For each additional setting in which racial discrimination was reported there was a nearly one-third increased odds of being a moderate/heavy drinker (OR: 1.28, CI: 1.05–1.56, p = 0.01) (Table 4b, Model 1). In our moderation model, the number of settings participants reported having experienced racial discrimination had no statistically significant effect on weekend alcohol use or interaction with racial socialization, such that the relationship between racial discrimination and weekend alcohol use was not dependent on frequency of racial socialization (Table 4b, Model 2).

For each additional setting in which racial discrimination was reported there was a nearly one-third increased odds of using alcohol at problematic levels (OR: 1.31, CI: 1.10–1.70, p = 0.04) (Table 4c, Model 1). In our moderation model, the number of settings participants reported having experienced racial discrimination had no statistically significant effect on problem alcohol use or interaction with racial socialization such that the relationship between racial discrimination and problem alcohol use was no dependent on frequency of racial socialization (Table 4c, Model 2).

4. Discussion

In a sample of African American residing in New York City, experiences of racial discrimination increased the risk of alcohol use. Specifically, the risk of weekend and problematic alcohol use increased with the greater number of setting in which racial discrimination was experienced. We did not find support for our hypothesis that the relationship between substance use and racial discrimination depended on levels of racial socialization. In other words, learning about race in childhood and adolescence did not prevent substance use or abuse associated with racial discrimination in adulthood. We also did not find a relationship between racial discrimination, racial socialization and being a lifetime cigarette smoker or using alcohol on the weekday.

Our findings are consistent with studies on the relationship between racial discrimination and problem alcohol use. A number of studies find a relationship between racial discrimination and severity of alcohol use such as heavy drinking and alcohol dependence (Borrell, LN, et al., 2007, Boynton, MH, et al., 2014, Gibbons, FX, et al., 2010 and Latzman, RD, et al., 2013). In these studies racial discrimination is measured in a variety of ways, in different populations and different aspects of racial discrimination tapped into (e.g., number of settings, frequency of racial discriminatory experiences) (Borrell, LN, et al., 2007, Boynton, MH, et al., 2014, Gibbons, FX, et al., 2010 and Latzman, RD, et al., 2013).

Our findings on the association between racial discrimination and weekend but not weekday alcohol use suggest that temporal patterns of alcohol consumption depend on employment status. Studies on motivation for weekday alcohol use find that use is associated with coping, usually with work related stress (Studer et al., 2014). It might be expected that racial discrimination would have an effect on alcohol use during the week to cope with a potentially racially hostile work environment. However, nearly half of our sample reported being unemployed. Moreover, settings in which racial discrimination was most frequently experienced were not work related (e.g., while getting service, on the street or in public settings, from the police or in the courts).

Our findings of no effect of racial discrimination on lifetime cigarette smoking are inconsistent with most studies on racial discrimination and cigarette smoking (Bennett, GG, et al., 2005, Borrell, LN, et al., 2007, Borrell, LN, et al., 2010, Clark, TT, 2014, Landrine, H and Klonoff, EA, 2000 and Purnell, JQ, et al., 2012). Multivariate analyses did suggest a positive association between racial discrimination and being a current cigarette smoker. The lack of any indication of an association with lifetime cigarette smoking, however, might be due to the greater effect of other factors associated with lifetime cigarette smoking such as age. Our sample comprised a mostly middle aged cohort. Lifetime cigarette smoking is higher among older adults, (Burns, DM, et al., 1997 and Holford, TR, et al., 2014) whose use started during a period of time when smoking related stigma was far less than it is today (Stuber, Galea, & Link, 2008). And our findings showed an increased odds being a lifetime cigarette smoker for older participants.

We did not find support for our hypothesis that racial socialization—learning about race—in childhood and adolescence moderates the relationship between discrimination and behaviors related to tobacco and alcohol use. However, our results suggest racial socialization might affect the relationship in a different way. Correlation analysis did show a moderate relationship between racial socialization and discrimination. Learning about race (i.e., racial socialization) might be necessary to attribute an unfair experience to racism in the first place (Bynum, MS, et al., 2007 and Lee, DL and Ahn, S, 2013). Future research should examine other ways that racial socialization affects the relationship between discrimination and substance use such as its indirect effects (i.e., mediation).

4.1. Strengths and limitations

Our findings should be contextualized by a couple limitations. The cross-sectional nature of our study does not allow us to infer causation. For example, we do not know if experiences of discrimination preceded substance use. Future research should examine the longitudinal relationship between racial socialization, discrimination and substance use. Finally, our measure of racial socialization did not assess message content. We propose that racial socialization messages provide a schema on how to prepare for and cope with racial discrimination. However, racial socialization messages vary (Lesane-Brown, 2006). Future research should examine the relationship between racial discrimination, racial socialization content and substance use.

5. Conclusions

Racial discrimination affects all Americans' health and health behaviors. Experiencing—and even inflicting (Samson, 2015)—a racial discriminatory act is a stressor that increases the risk of substance use (Bennett, GG, et al., 2005, Borrell, LN, et al., 2007, Borrell, LN, et al., 2010, Boynton, MH, et al., 2014, Clark, TT, 2014, Gibbons, FX, et al., 2010, Kwate, NOA, et al., 2003, Landrine, H and Klonoff, EA, 2000, Latzman, RD, et al., 2013 and Purnell, JQ, et al., 2012). Messages about race and racism appear to affect African Americans' ability to process and cope with unfair experiences. How race related messages affect responses to race based exclusion remains to be seen. Future research should examine racial socialization content and its direct effects on perceiving an experience as discriminatory and its indirect effect on substance use. In doing so, we may learn how best to teach race throughout the life course, and ultimately contribute to a reduction in substance related disparities.

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Contributors

A.B. Thompson conceived the study, contributed to the analysis plan, and led the interpretation of results and writing the article. M.S. Goodman developed the analysis plan, conducted the statistical analysis and contributed to the writing. N.O.A. Kwate originated the funding, and contributed to the analysis plan and to the writing.

Conflict of interest

The authors declare no conflicts of interest.

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Predicting Real-world Functional Milestones in Schizophrenia

Anna-Karin Olsson [1, 2, *], Fredrik Hjärthag [2], Lars Helldin [1, 2]

[1] Department of Psychiatry, NU Health Care, Trollhättan, Sweden
[2] Department of Psychology, Karlstad University, Karlstad, Sweden

* Corresponding Author. E-mail: anna-karin.olsson@vgregion.se

Abstract. Schizophrenia is a severe disorder that often causes impairments in major areas of functioning, and most patients do not achieve expected real-world functional milestones. The aim of this study was to identify which variables of demography, illness activity, and functional capacity predict patients' ability to attain real-world functional milestones. Participants were 235 outpatients, 149 men and 86 women, diagnosed with schizophrenia spectrum disorder. Our results showed that younger patients managed to achieve a higher level of functioning in educational level, marital status, and social contacts. Patients' functional capacity was primarily associated with educational level and housing situation. We also found that women needed less support regarding housing and obtained a higher level of marital status as compared with men. Our findings demonstrate the importance of considering current symptoms, especially negative symptoms, and remission stability over time, together with age, duration of illness, gender, educational level, and current functional capacity, when predicting patients' future real-world functioning. We also conclude that there is an advantage in exploring symptoms divided into positive, negative, and general domains considering their probable impact on functional achievements.

Keywords: Schizophrenia; Functional capacity; Real-world functional milestones; Predictive factors.

1. Introduction

Schizophrenia is a severe and complex mental disorder that often has disabling consequences for the patients. It involves impairment in one or more major areas of functioning, and most patients do not achieve desired and expected real-world functional milestones (Cardenas et al., 2013 and Harvey, 2013). Educational level, independence in housing, current work situation, marital status, and quantity and quality of social contacts are examples of real-world functional milestones that objectively describe patients' functional achievements. There is, however, no consensus about what constitutes functioning (Gupta et al., 2012). For example, real-world functioning could be described as patients' achieved functional milestones (Harvey, 2013), as observer-rated reports of patient's behavior and skills (Schneider and Struening, 1983), or as functional capacity (Patterson et al., 2001).

The use of real-world functioning variables as measures of function could be problematic as they are not sensitive to manifest changes (Mantovani et al., 2015). Moreover, environmental factors may influence these indicators (Harvey et al., 2009, Helldin et al., 2012 and Priebe, 2007). In order to avoid that the assessments of patients' function are affected by environmental factors – such as the prevailing culture, the welfare system, and the labor market – the use of performance-based assessment instruments measuring functional capacity has increased in recent years (Mantovani et al., 2015 and Moore et al., 2007). One of these performance-based instruments is the University of California, San Diego (UCSD) Performance-Based Skills Assessment (UPSA; Green et al., 2011 and McKibbin et al., 2004). Functional capacity can be assessed at a clinic, in a set environment, where patients perform everyday tasks through role-playing (Bowie et al., 2008, McKibbin et al., 2004 and Patterson et al., 2001).

The discrepancy between a person's potential to perform (functional capacity) and what he or she actually does perform (real-world functional milestones) still remains to be investigated. Previous studies have found real-world functioning to be predicted by functional capacity (Bowie et al., 2008 and Ho et al., 2013), negative symptoms, and cognitive deficits (Bowie et al., 2008). Real-world functioning and functional capacity correlate moderately (Leifker et al., 2011) and explain 17% of each other's variance (Menendez-Miranda et al., 2015). Functional capacity also seems to mediate the relationship between neuropsychological functioning and real-world functioning (Bowie et al., 2008; Ho et al., 2013 and Mantovani et al., 2015). Measures of cognitive performance account for 25–50% of the variance in real-world functioning (Fett et al., 2011 and Harvey et al., 1998), whereas gender, ethnicity, and age have traditionally been the most important demographic factors for predicting real-world functioning (Gould et al., 2012). It is clinically important to explore if other factors exist and, if so, to understand how they influence real-world functioning (Harvey and Strassnig, 2012). Harvey (2013) has suggested that real-world functioning, as measured by separate scales for social, vocational, and residential functioning, should be preferred over combined global functioning scores.

Taking this complex background into account, the aim of this study is to identify which variables of demography and illness activity, together with functional capacity, predict patients' ability to achieve real-world functional milestones. Further, we investigate how these predictors contribute to explain the five functional milestones Educational level, Current work situation, Housing situation, Marital status, and Social contacts.

2. Methods

2.1. Procedure

Data collection took place within the ongoing project Clinical Long-term Investigation of Psychosis in Sweden (CLIPS), which investigates psychiatric outpatients. Patients partaking in the project were rated annually on several domains, including demographic and functional variables (e.g., age, gender, social function, work capacity, and ability to live independently) and clinical variables (e.g., psychiatric symptoms and remission status). The assessments of demographic and illness activity variables were administered by a case manager with in-depth knowledge of the patient and highly skilled in assessment methodology, and an occupational therapist measured patients' functional capacity. Exclusion criteria for participation in the CLIPS project were comorbidities such as mental retardation and autism. For this study, a total of 259 patients were assessed, and 24 patients were excluded: 17 because of missing data for demographic and illness activity variables from the same assessment session, and seven because they had not been assessed for all functional capacity items.

2.2. Participants

In this study, 235 patients participated, 86 women and 149 men, with a mean age of 49.9 years (SD=11.4, between 24 and 74years of age). The mean age of the women was 51.5 years (SD=12.3) and the mean age of the men was 48.98 years (SD=10.8). An independent t test (p=0.12) showed no significant difference between men and women regarding age. Mean age at illness onset was 26.02 years (SD=10.4): 27.68 years (SD=11.4) for the women and 25.02 years (SD=9.7) for the men, with no significant difference (p=0.08). Among the study participants, 157 patients were diagnosed with schizophrenia, 49 patients with schizoaffective disorder, and 29 patients with delusional disorder. At the time of assessment, 117 of the 235 participants were in remission. The mean of the Global Assessment of Functioning Scale (GAF), rated by the case manager, was 45 points, with a variation between 30 and 70 points (SD=7.8).

2.3. Measures

2.3.1. Demographic variables

The demographic variables were gender, age, age at illness onset, and illness duration.

2.3.2. Illness activity variables

The variables investigated to measure illness activity were current symptoms and remission status stability during the past three years. Patient symptoms were examined using the Positive and Negative Syndrome Scale (PANSS) by Kay et al. (1987). The PANSS is an interview and observation-based instrument with 30 items divided into three domains: positive symptoms (P 1–7), negative symptoms (N 1–7), and general symptoms (A 1–16). Each item is rated on a seven-point scale where low scores indicate low levels of symptom severity and high scores indicate high levels of symptom severity (Kay et al., 1987). Patients were assessed using a Swedish version of the Structured Clinical Interview – Positive and Negative Syndrome Scale (Lindström et al.,1994). Patients in remission can be identified by examining eight selected items from the PANSS (Andreasen et al., 2005; Lasser et al., 2007).

All patients were regularly followed up by their case manager between assessments over three years. To be in stable remission, the patient had to be in remission at all times measured and with no relapses in between.

2.3.3. Functional capacity

Functional capacity was assessed using the University of California, San Diego (UCSD) Performance-Based Skills Assessment – Brief (UPSA-B; Mausbach et al., 2007), a performance-based observational instrument assessing patients' ability to cope with everyday tasks. The instrument assesses functional capacity in two domains: finance (counting money and paying bills) and communication (e.g., making an emergency call, rescheduling a medical appointment). There are a total of 19 items in the UPSA-B and, by using a standardized calculation of the scores, the total score ranges from 0 to 100 (Mausbach et al., 2007). A study of the Swedish version of the UPSA-B found that this version of the instrument has good psychometric properties regarding both validity and reliability (Olsson et al., 2012).

2.3.4. Functional milestones

Three items from the Strauss-Carpenter scale (Strauss and Carpenter, 1972) were used to assess real-world functional milestones. The chosen items, with three response alternatives, were Current work situation (sickness benefit/unemployed, part time job, or full-time job), Housing situation (supported housing, living with parents, or independent housing), and Social contacts (seldom contact with others, contact with others once a week, or contact with others more than once a week). The original Strauss-Carpenter scale was modified by Lindström et al., 1995 and Helldin et al., 2007 included items for Educational level (primary, secondary, or higher education) and Marital status (single, separated, or married/cohabiting). Information was collected via medical records as well as from interviews with patients, relatives, and medical staff.

2.4. Analyses

The demographic, illness activity, and functional capacity variables and their covariance with functional milestones were examined separately. In the descriptive part of the results, the mean (M), standard deviation (SD), and in some cases percentages are reported. Correlations between continuous variables were determined using Spearman's rho. The Chi-Square test ($\chi 2$) and the Kruskal-Wallis test (H) with multiple comparison tests were used to analyze differences in demographic and clinical variables between independent categories of functional milestones. Ordinal logistic regression analyses were done with the five functional milestones (Educational level, Current work situation, Housing situation, Marital status, and Social contacts) as dependent variables, and the demography, illness activity, and functional capacity variables – which in the previous step showed significant results (correlations or significant group differences) for each of the functional milestones – as predictor variables. As none of the predictors were significantly associated with Current work situation, this functional milestone was excluded from further analyses. The results are presented as odds ratios and 95% confidence intervals.

3. Results

Descriptions of patients' demographic, illness activity, functional capacity, and real-world functional milestones data are presented in Table 1. The distribution of data differs between the categories of the functional milestones: educational level has an even distribution compared with Current work situation where 88.5% of the patients are in the same category (sickness benefit/unemployed).

Demographic, illness activity, and functional capacity variables (predictors) were tested for differences between categories of each functional milestone (criterion variables; see Table 2). None of the predictors were significantly associated with Current work situation, so this functional milestone was excluded from further analyses. Most independent variables showed significant group differences for the functional milestones Housing situation, Marital status, and Social contacts. Differences were most common between the lowest (Group 1) and highest (Group 3) levels of functioning. Age correlated with all the functional milestones except for Current work situation. Due to correlations between age, age at illness onset, and years of illness duration (rs=0.615 and 0.425, p=<0.01), only the patients' age was selected as a predictor in the following regression analyses in order to avoid multicollinearity.

Ordinal logistic regression analyses were conducted to examine the impact of the demographic, illness activity, and functional capacity variables on variance in each of the presented real-world functional milestone variables. The functional milestones (except for Current work situation) were used as dependent variables, and the demographic (except for age at illness onset and illness duration), illness activity, and functional capacity variables that in the first step of the analyses showed a significant result were used as predictors (Table 3).

Educational level was associated with functional capacity and age. An increase in functional capacity (expressed in higher UPSA-B scores) was associated with an increase in the odds of higher level of education, with an odds ratio of 1.036 (95% CI, 1.019–1.054), Wald $\chi 2$ (1)=17.635, p=<0.000. A closer examination of UPSA-B mean scores showed that they were lower (M =58.41) for patients whose highest educational level was primary school compared with those who had completed secondary school (M=75.03) or higher education (M=81.56). Patients with primary school as highest educational level were older (mean age 54.50 years) compared with patients who had completed secondary school (M=46.22 years) or higher education (M=47.14 years). The ordinal logistic regression model explained 24.4% of the variance.

Housing situation was associated with gender (OR=0.099), PANSS general symptoms (OR=0.889), and functional capacity (OR=1.033). A closer examination revealed that male patients (12% compared with 6% of the female patients), patients with more severe general symptoms (M=35.48), and patients with lower functional capacity (M=49.35) lived in supported housing to a higher degree. There were also gender differences in patients who lived together with their parents (9% of the men compared with 1% of the women) and in those who lived independently (79% of the men compared with 93% of the women). Patients who lived in independent housing had a mean score of 70.56 for functional capacity and 28.06 for PANSS general symptoms. The ordinal logistic regression model explained 27.3% of the variance.

The odds ratio for male patients to achieve a higher level in the functional milestone Marital status was 0.246 (95% CI, 0.146–0.479) times that of female patients–a statistically significant effect, Wald $\chi 2$ (1)=19.286, p=<0.001. Male patients were more often single (75% compared with 41% for women), and 59% of the women were or had been married/cohabiting compared with just 25% of the men. Marital status was also associated with age (OR=0.966) and PANSS positive symptoms (OR=0.915). A closer examination showed that patients who were single had a lower mean age (47.39 years) and more severe positive symptoms (M=13.32) compared with those who were married (mean age 51.95 years, positive symptoms mean score 9.41) and those who were separated (mean age 55.66 years, positive symptoms mean score 12.76). The ordinal logistic regression model explained 24.4% of the variance.

Frequency of social contacts was associated with age (OR=0.942) and PANSS negative symptoms (OR=0.883). A closer examination showed that patients who had more contact with others and met friends and/or families more than once a week had a lower mean age (48.09 years) and less severe negative symptoms (M=13.77) compared with those who met friends and/or families once a week (mean age 52.42 years, negative symptoms mean score 17.18) and those who only had short and temporary contacts with others (mean age 54.45 years, negative symptoms mean score 22.10). The ordinal logistic regression model explained 25.8% of the variance.

4. Discussion

This study, which has a large sample across a wide span of ages and years of illness, shows that patients' age, functional capacity, and gender correlate with several functional milestones: younger patients have a higher functional capacity, and women more often attain higher real-world functional milestones. Our findings also show that there are advantages of dividing symptoms into positive, negative, and general domains as these different symptom domains are associated with different functional milestones.

As expected, there are strong associations between age, illness duration, and attainment of functional milestones. The findings of Barnes and Pant (2005) show that functional impairment in patients with schizophrenia and other psychotic disorders primarily occurs within 5–10 years after illness onset. In the current study, the mean illness duration is close to 24 years, which means that, based on the above reasoning, a majority of the patients' functional impairment can be considered stable. However, the age at illness onset does not have an impact on the functional milestones, except for Marital status. Prevalence of schizophrenia does not differ between men and women, but there may be differences in the course of illness even though no previous consensus has been established (Siegel et al., 2006). Some studies show that women with schizophrenia have a better prognosis than men. This could be explained by later onset of illness among women, which in turn leads to higher premorbid functioning, lower rates of negative symptoms, and better social functioning (Goldstein and Walder, 2006 and Häfner et al., 1998). The mean age for illness onset was 26.02 years in the present study, whereas age of illness onset is generally between 15 and 35 years–in late adolescence or early twenties for men and later twenties or thirties for women (Thomsen, 1996). The later illness onset among women might also explain why they reached a higher level than men in marital status in our study. Furthermore, fewer women lived in supported housing or together with their parents. And 79% of the men and 93% of the women lived independently.

Functional capacity mainly correlates with educational level and the ability to live independently in the community. These findings are well in line with previous results (Gould et al., 2012, Mausbach et al., 2007 and Mausbach et al., 2008; McIntosh et al., 2011). The functional capacity did not significantly predict patients' current work situation, as in a previous study (Mausbach et al., 2011). In our study, only fourteen patients (6%) worked or studied full time, which could be compared with 12% found in a study by Lindström et al. (2007). Hence, unemployment or early retirement are well-recognized outcomes of schizophrenia (Svedberg et al., 2001), and unemployment rates vary across countries and time. The study of Kooyman et al. (2007) shows that 11.5% of a British sample were employed or in sheltered employment, while corresponding rates were 12.9% of a French sample and 22% of a United States sample. Previous findings also show that environmental factors, such as the labor market, may impede the achievement and use of functional skills (Harvey et al., 2009, Helldin et al., 2012 and Priebe, 2007).

Social skills are often linked to a person's ability to keep a job (Shannon et al., 2006). Our analyses of group differences show that patients who remained in remission continuously during the past three years had a higher ability for social contacts, which is in line with previous findings (Helldin et al., 2007). Furthermore, these results emphasize the importance of continuing the pursuit of good symptom control – especially for negative symptoms – and remission stability in order to increase the chances of maintaining high functioning. Previous studies have reported that negative symptoms correlate with real-world functioning (Ventura et al., 2009), but our results show that negative symptoms only predict the functional milestone Social contacts. Furthermore, the present study shows that dividing symptoms into positive, negative, and general domains could be useful for exploring real-life outcomes.

This study has some limitations. Because it is a naturalistic study design, it is difficult to know how representative this specific sample is for the patient population in general. A previous study from the CLIPS project reported that 670 patients fulfilled the inclusion criteria and were invited to join the project (Helldin et al., 2008), and about 35% of these possible participants for the project were included in the present study. Using retrospective data, such as age at illness onset and illness duration, requires extra caution due to, for example, patients' difficulties to recall past events. To reduce such bias, these retrospective data were collected from, and compared with, different sources such as medical records, patients, relatives, and medical staff. Another possible problem, for which we used non-parametric statistics, is the skew distribution among categories that were found in some variables. One strength of this study is that the patients' age as well as illness duration spans across a much wider range than is usual in this type of study. Our results thus provide a more representative picture, which will help create better conditions for daily clinical work.

There is a growing interest in developing remission criteria for functioning similar to those that exist for symptoms (Lançon et al., 2012 and Spellmann et al., 2012). Variables from several domains are probably required in order to clarify patients' ability to cope with everyday activities. Our results demonstrate that patients' current symptoms – especially negative symptoms – and remission stability over time, together with their age, duration of illness, gender, educational level, and current functional capacity, should be taken into consideration as variables in future studies describing real-world functioning.

Ethical approval

The study was approved by the Ethical Research Committee at the University of Gothenburg, Sweden (Approval number: Ö537-99, 507-04, 438-10, 423-14), and the investigation was carried out in accordance with the latest version of the Declaration of Helsinki.

Conflict of interest

No authors declare any conflict of interest.

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Acrylamide Formation in Vegetable Oils and Animal Fats During Heat Treatment

G. Daniali [1], S. Jinap [1, 2, *], P. Hajeb [1], M. Sanny [1], C.P. Tan [3]

[1] Department of Food Science, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia
[2] Department of Food Safety, Institute of Food Security, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia
[3] Department of Food Technology, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

* Corresponding Author. E-mail: jinap@upm.edu.my, sjinap@gmail.com

Abstract. The method of liquid chromatographic tandem mass spectrometry was utilized and modified to confirm and quantify acrylamide in heating cooking oil and animal fat. Heating asparagine with various cooking oils and animal fat at 180 °C produced varying amounts of acrylamide. The acrylamide in the different cooking oils and animal fat using a constant amount of asparagine was measured. Cooking oils were also examined for peroxide, anisidine and iodine values (or oxidation values). A direct correlation was observed between oxidation values and acrylamide formation in different cooking oils. Significantly less acrylamide was produced in saturated animal fat than in unsaturated cooking oil, with 366 ng/g in lard and 211 ng/g in ghee versus 2447 ng/g in soy oil, followed by palm olein with 1442 ng/g.

Keywords: Acrylamide; Vegetable oils; Animal fats; LC–MS/MS; Oxidation values.

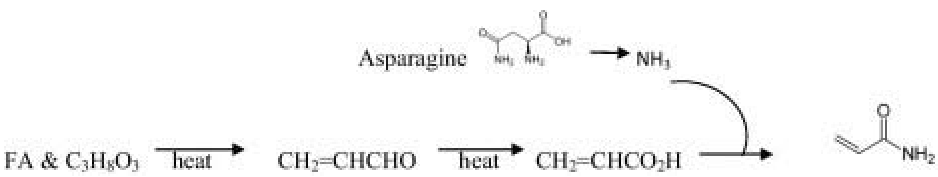
1. Introduction

Acrylamide (2-propenamide) is a hydrophilic compound that has been classified as a probable human carcinogen. It is present in numerous fried foods such as potato crisps, French fries, breakfast cereals, coffee beans, snacks and bakery products. Acrylamide is a common toxic compound produced in oil after the frying of food (Matthaus et al., 2004 and Mestdagh et al., 2005).

Acrylamide is mainly produced by the Maillard reaction involving asparagines and reducing (Mottram, Wedzicha, & Dodson, 2002). The Maillard reaction occurs when free amino group with a reducing sugar to form Amadori products. In the next step, the degradation of Amadori products follows; the products are hydrolyzed to form 3-aminopropionamide, which can degrade to a further extent through the elimination of ammonia to form acrylamide when heated. Alternatively, the decarboxylated Schiff base can decompose directly to form acrylamide via elimination of an imine (Zyzak et al., 2003). There are some similarities in the formation of acrylamide, through Maillard and lipid pathway. First, amino acids in both of the reactions are sources of ammonia. Furthermore, both of the pathways require the carbonyl source in order for acrylamide formation to occur (Yasuhara et al., 2003 and Zyzak et al., 2003).

Acrylamide is formed in frying oil due to the degradation of the oil or to the interaction between carbonyl groups and other components (such as amino acids from the food) under high temperature (Aladedunye & Przybylski, 2011). These reactions are found to be related to the degradation and interaction between oxidants and other components and the formation of certain toxic compounds in deep fat frying oil after heat processing (Ou et al., 2010). Also, certain secondary lipid oxidation products may convert amino acids into either their corresponding Strecker aldehydes or vinylogous derivatives, depending on the amount of oxygen present in the reaction (Hidalgo and Zamora, 2007 and Zamora et al., 2007), thereby suggesting that a potential route for the contribution of these secondary lipid oxidation products to acrylamide formation in thermally treated foods. Under appropriate conditions, oxidized proteins will result in the degradation of asparagine to acrylamide and contribute to the formation of this contaminant during food processing.

Previous studies have shown that degradation products of amino acids can also be produced during the Maillard reaction (Stadler et al., 2004 and Tareke et al., 2002). There are several reports regarding acrylamide formation from asparagine with carbonyl compounds. Heating asparagine with octanal, 2-octanone or 2,3-butanedione may result in the formation of various amounts of acrylamide (Becalski, Lau, Lewis, & Seaman, 2003). Glycolaldehyde and glyceraldehyde produce approximately 2 times and 1.75 times more acrylamide than glucose with asparagine respectively (Yaylayan, Wnorowski, & Perez Locas, 2003). Although according to Zamora and Hidalgo (2008), the presence of primary lipid oxidation products, or even unoxidized lipids under oxidizing conditions, is the only prerequisite needed to observe a positive contribution of lipids to acrylamide formation during food heating. It has been known for over half a century that α-amino acid produces ammonia via Strecker degradation in the presence of a carbonyl compound (Schonberg & Moubasher, 1952). Acrylic acid, which is an oxidation product of acrolein and glycerol, produces a significant amount of acrylamide with ammonia (Yasuhara et al., 2003). A fatty acid (such as pure linoleic acid and linolenic acid hydroperoxides) backbone showed by Ewert, Granvogl, and Schieberle (2014) to be the key precursor structure for acrolein formation. The hypothesized formation mechanisms of acrylamide from amino acids and lipids are shown below:



When oil is heated at temperatures above the smoke point, glycerol is degraded to acrolein and the formation of acrolein is known to increase directly with the increase in unsaturation in the oil. The oil is hydrolyzed into glycerol and fatty acids and acrolein is produced by the elimination of water from glycerol by a heterolytic acid-catalysed carbonium ion mechanism followed by oxidation (Uchida et al., 1999). Acrolein can also be produced as a result of oxidation of polyunsaturated fatty acids and their degradation products. Acrolein is also found to form in vivo by the metal-catalysed oxidation of polyunsaturated fatty acids, including arachidonic acid (Esterbauer, Schaur, & Zollner, 1991).

According to Pedreschi, Kaack, and Granby (2006) the free asparagines and the reducing sugars (acrylamide precursor) can leach out from the surface layer of cut potato to the media. It has also been shown by Mestdagh et al. (2005) that acrylamide precursor could indeed be transferred to the frying oil.

The objectives of this study are to determine the effect of asparagine on the formation of acrylamide in vegetable oils and animal fats and to assess the formation of acrylamide from asparagine in vegetable oils and animal fats having different oxidation values. Further detection of the acrylamide level present in oils has been carried out through the use of the analytical method.

2. Materials and methods

2.1. Materials

Sesame, soy bean, sunflower, corn, olive and palm olein oils, animal fat ghee and lard had been purchased from a local market (Serdang, Malaysia). Isotopic [13C3] acrylamide (isotopic purity, 99%) used as an internal standard was obtained from Cambridge Isotope Laboratories (Andover, MA, USA) at the concentration of 1 mg/ml and diluted to 50 ppb to form a working solution, which was used in the sample, standard and spiking acrylamide preparation. Acrylamide (standard for GC, assay ⩾99.8%) was obtained from Sigma–Aldrich (Hong Kong, China) in powder form, whereas Oasis MCX 3 cc (60 mg) liquid phase and Oasis HLB 3 cc (60 mg) solid phase extraction cartridges were purchased from Waters Corporation (Waters, Milford, MA, USA). Certified reference material

(CRM) toasted bread was purchased from European reference materials (ERM) (Geel, Belgium). Other chemicals were obtained from Fisher Scientific (Leicestershire, UK).

2.2. Experimental design

A model system was designed to study the influence of asparagine concentrations on the formation of acrylamide in cooking oils. Four different concentrations of asparagine were examined (0.1, 0.2, 0.3, 0.5 mg) in two types of vegetable oil (soybean and sunflower oil) and one type of animal fat (lard). The information obtained (the best amount of asparagine, 0.2 mg according to Table 3) was used to determine the acrylamide concentration in different vegetable oils and animal fats (sesame, soy bean, sun flower, corn, olive, palm olein oils, animal fat ghee and lard). Ten grams each of cooking oil and animal fat were mixed with 0.2 mg asparagine, transferred into a Petri dish and heated up at 180 °C (180 °C is the actual temperature in the probe oven when it was set at 188 °C) for 30 min. After cooling, the acrylamide concentration was determined. The experiment was replicated thrice. The oxidation values (peroxide value, iodine value and anisidine value) of the oils were measured before and after heat treatment. Correlations were drawn between the oxidation values and acrylamide formation for both oils and fats.

2.3. Instrumentation

Liquid chromatography–mass spectrometry (LC–MS-MS) analysis was performed on a TSQ Quantum Ultra (Thermo Scientific, San Jose, CA, USA) triple quadrupole mass spectrometer which was connected to an Accela High Speed LC quaternary high pressure pump and an Accela autosampler (Thermo Finnigan, San Jose, CA, USA). An atmospheric pressure chemical ionization (APCI) source was used to produce and introduce ions into the mass spectrometer, equipped with X-calibur software (Thermo Scientific, San Jose, CA, USA) for separation, detection and quantification. The analytical column was a porous graphitic carbon Hypercarb column (2.1 mm × 50 mm ID; 5 µm) (Thermo Electron, Bellafonte, PA, USA) maintained at 45 °C. The mobile phase was 100% water and the flow rate was maintained at 150 µl/min. The injection volume was 10 µl. Acrylamide was analyzed using the APCI in positive ion mode. Selective reaction monitored mode (SRM) was acquired with the characteristic fragmentation transitions m/z 72 > 55 ([M+H–NH3]+) for acrylamide and m/z 75 > 58 for [13C3] acrylamide. The APCI-optimized parameters were: discharge current, 4 µA; capillary temperature, 250 °C; sheath gas pressure, 10 arb and auxiliary gas pressure, 12 arb. Tube lens offset voltages were optimized for acrylamide using the automated optimization procedure in syringe infusion mode provided by the manufacturer. The argon collision gas pressure was adjusted to 2.9e-5 psi (1.5 mTorr) for MS/MS. A spectrophotometer (Spectronic 20 Ginisys, Rockford, IL, USA) with a wavelength range of 340–950 nm and a nominal spectral band width of 20 nm (consistent over the entire wavelength range) was used in the study to determine anisidine values.

2.4. Determination of peroxide values

The primary products of lipid oxidation and hydro peroxides are generally referred to as peroxides. Peroxide values were determined by using conventional iodometric titration with thiosulfate (AOAC, 1984). The sample was suspended in 25 mL of an acetic acid/chloroform (3:2) mixture and 0.5 mL of saturated KI. The resulting mixture was kept in the dark for 5 min, after which 70 mL of distilled water and 1 mL of a 1% (w/v) solution of starch paste were added. The mixture was then titrated with sodium thiosulfate 0.01 N. The POV of the sample was calculated by using the following equation:

S is the titration of sample (mL), B is the titration of blank (mL), while N is the normality of thiosulfate solution and W is the weight of sample (g) (AOAC, 1984).

2.5. Determination of iodine values

Iodine values (IVs) were used to determine the amount of unsaturated fatty acids, which, in the form of double bonds, reacted with iodine compounds. The iodine values of the oils extracted from the commercial samples were determined according to AOCS (1993). Weighed samples were placed in a 500 ml conical flask followed by the addition of 20 ml of carbon tetrachloride and 25 ml of Wijs reagent. A stopper was inserted and it was rotated and placed in the dark for an hour; after which 20 ml of potassium iodide (10% concentration) was added to the flask, followed by 100 ml of pure water. This mixture was titrated with 0.1 M of sodium thiosulfate solution until the yellow color disappeared.

A few drops of starch solution were added before continuing the titration until the blue color disappeared. The IV of the sample was calculated by using the following equation:

C is the concentration of the sodium thiosulfate solution (mol/L), V1 is the volume (mL) of sodium thiosulfate solution used for the blank test, V2 is the volume (mL) of sodium thiosulfate solution used for the sample test and M is the mass (g) of the sample.

2.6. Determination of anisidine values

Anisidine values (AnVs) represented the level of non-volatile aldehydes, primarily 2-alkenes, present in the fat. Solution (a) was prepared by dissolving 0.500 g of oil in trimethylpentane with the volume brought to 25.0 ml with the same solvent using a volumetric flask. Solution (b) was prepared by adding 1.0 ml of a 2.5 g/L solution of p-anisidine in glacial acetic acid and then shaken in a dark place. A reference solution was prepared by adding 5.0 ml of trimethylpentane to 1.0 ml of a 2.5 g/l solution of p-anisidine in glacial acetic acid and then shaken in the dark, until the absorbance of solution (a) at the maximum at 350 nm using trimethylpentane as the compensation liquid was measured. The absorbance of solution (b) was measured at 350 nm exactly 10 min after its preparation using the reference solution as the compensation liquid. The anisidine value was calculated from the expression:

A1 is absorbance of solution (b) at 350 nm, A2 is absorbance of solution (a) at 350 nm and W is the weight of the oil being tested (a) in grams (AOCS, 1993).

2.7. Analysis of acrylamide

2.7.1. Extraction

Modified methods of Ehling et al., 2005 and Daniali et al., 2013 and Lim, Jinap, Sanny, Tan, and Khatib (2013) had been applied to extract acrylamide from the samples. l-asparagine (0.2 g) was weighed and added to 10 mL of oil using a volumetric flask, heated up in a Petri dish and heated in the oven at 180 °C for 30 min. The mixture was stirred with a magnetic stirrer and allowed to cool to room temperature. A 0.5 g sample of the heated mixture of oil and l-asparagine was transferred to a 50 ml centrifuge tube and the volume was adjusted to 10 mL with 50 ppb 13C3-labelled acrylamide as an internal standard. Samples were mixed using a reciprovertical shaker (RS-1, Jeio Tech Co., Gyeonggi-do, Korea) for 30 min at medium speed (ca. 285 pulses/min). The homogenate was centrifuged using a refrigerated centrifuge (3–18 K, Sigma, Gillingham Dorset, UK) at 10,000 rpm (10956 RCF ×g) for 30 min at 4 °C. A syringe filter (0.45 μm) was used to filter an approximately 4 ml aliquot beneath the oil layer. Oasis HLB and Oasis MCX cartridges were conditioned and equilibrated with 3 ml of methanol followed by 3 ml of water before being loaded with the filtrate. The filtrate (2 mL) was passed through the Oasis HLB cartridge (Waters, Milford, MA, USA) gravitationally and discarded. The acrylamide containing fraction from the Oasis HLB cartridge was eluted with 2 ml of water; the eluent was collected and then loaded onto the Oasis MCX cartridge (Waters, Milford, MA, USA). The collected eluent was transferred to an amber vial for LC–MS/MS analysis.

2.7.2. Quantitation of acrylamide

Monomer [13C3] acrylamide was used as internal standard. Acrylamide in the cooking oils was determined from a calibration curve constructed by plotting the peak area ratios (m/z 55 and m/z 58) versus the concentrations of neat acrylamide injected with a constant amount of [13C3] acrylamide (50 ng/mL).

2.8. Validation of the acrylamide determination method

2.8.1. Calibration curve

Acrylamide in the oil samples was quantified using the ion of acrylamide at 72 m/z for acrylamide and the ion of its internal standard at m/z 75 m/z for [13C3]-acrylamide. The calibration curve was constructed by plotting peak area ratios (peak area of ions m/z 72/75) against the corresponding substance concentrations (μg/kg). The acrylamide concentrations in the sample extracts were calculated from the calibration curve by plotting the area ratio of m/z 72/75 ions found in the sample. The LC–MS/MS results were calibrated with two calibration curves determined by seven standard calibration solutions (AOAC, 2002).

2.8.2. Limit of detection (LOD) and limit of quantification (LOQ)

The limit of detection (LOD) and limit of quantification (LOQ) were determined by using the lowest calibrator concentration in seven experiments and were established at a signal/noise ratio (S/N) > 3 and (S/N) > 10 respectively (AOAC, 2002).

2.8.3. Recovery of acrylamide

The recovery of acrylamide from the heated oils was assessed by spiking acrylamide at a range of concentrations (50–5000) μg/kg into different heated oils. Each measurement was performed in seven replications and the recovery result was reported as the mean of the 7 determinations (AOAC, 2002).

2.8.4. Repeatability and reproducibility of acrylamide determination

The repeatability was determined by six analyses of a spiked sample. The levels spiked were 100 μg/kg and 500 μg/kg in one day. The reproducibility was determined by six analyses of a spiked sample on different days. The levels spiked were 100 μg/kg and 500 μg/kg. The repeatability and reproducibility were expressed as relative standard deviations (RSD%), (AOAC, 2002).

2.8.5. Certified reference material

Certified reference materials (CRMs) were reference materials that were homogeneous and stable with respect to one or more specified properties and for which traceability and values of uncertainty at a stated level of confidence had been established where applicable. Toasted bread with a certified value of 425 ng/g acrylamide and uncertainty value of 29 ng/g was obtained from the European commission.

3. Statistical analysis

Analysis of variance (ANOVA) was used to analyze the significance of differences between acrylamide concentrations in different cooking oils. The ANOVA analysis was performed by using Minitab (Release 14 for Windows, Pennsylvania, USA). Significance was determined at the 95% confidence level ($p < 0.05$) whilst Tukey's test was used for further statistical analysis.

4. Results and discussion

Before the method for acrylamide determination was used in this study, it was validated for linearity and recovery to assess its accuracy. The method used had a regression coefficient of 0.9998, equation Y = 0.0869983 + 0.0170771X, LOD and LOQ was 2 and 5 μg/kg respectively. Recovery was used to determine whether analyte detection was affected by differences in the diluent used to prepare the standard curve and the sample matrix. This method showed 104.2, 98.3, 99.6, 107.7 and 100.3% for 50, 100, 500, 1000 and 5000 μg/kg, respectively (Table 1). These recovery values were in the acceptable range according to the AOAC (2002). Repeatability and reproducibility were 3.40–6.25 and 1.08–5.68 on the same day; and were 5.00–7.98 and 0.50–7.86 on different days. These data meet the requirements of the guidelines for standard methodological performance (AOAC, 2002).

The method found that 426 ± 1 ng/g of acrylamide had an uncertainty value of 29 ng/g when it was used on the toasted bread certified reference material (CRM) with a certified acrylamide level of 425 ng/g (Table 5). The repeatability and the reproducibility tested on the same day were found to be 3.40–6.25 and 1.08–5.68; and those on different days 5.00–7.98 and 0.50–7.86 respectively (Table 2). The criteria for confirmation of identity in this method were in agreement with those proposed by Cheng, Kao, Shih, Chou, and Yeh (2009) and Chuang, Chiu, and Chen (2006), which had a detection limit of 3 μg/kg, with the recovery ranged from 95 to 113%. The coefficient of variation ranged from 1.3 to 10.0% for the repeatability test and 3.3 to 6.9% for the reproducibility test. Lucentini et al. (2009) had reported the limit of detection and limit of quantification for acrylamide to be 0.2 ng/ml and 0.8 ng/ml respectively. Repeatability given as RSD was <5 and <15% for the LC–MS/MS. These recent works showed that the present method can be utilized for acrylamide detection in oil samples (Cheng et al., 2009 and Lucentini et al., 2009).

4.1. Acrylamide formation in cooking oil and fat

A model study was designed to determine the optimum amount of asparagines added to be used in the experiment. Soy bean oil, sunflower oil and lard were used. The results found that when asparagine was heated in the absence of lipid (control), acrylamide was not produced. However, when different concentrations of asparagine were heated with the cooking oil, acrylamide was produced (Table 3). The formation of acrylamide in oil/asparagine reaction mixtures of 0.1 asparagine was significantly different ($P < 0.001$) compared to the other concentrations for both cooking oils and lard i.e. 18,100 ± 200 and 23,200 ± 300 ng/g ($p < 0.001$) for soy bean oil; 17,700 ± 200 and 24,100 ± 300 ng/g for sunflower oil and 324 ± 10 and 408 ± 11 ng/g ($p < 0.001$) for lard. However, there was no significant difference ($p > 0.05$) between the rest of the concentrations when more than 0.2 g of asparagine was added to either oil. Therefore, 0.2 mg of asparagine was used in all experiments.

One of the major chemical reactions occurring in oil during heat processing was lipid oxidation, which started with the formation of hydroperoxide and proceeded via radical mechanisms. The oxidation values in different types of oil before heat treatment were measured (Table 4). The highest peroxide value was found in olive oil (22.8 ± 0.7) and the lowest was in sesame oil (1.9 ± 0.1). The highest iodine value was found in soy oil (120.9 ± 3.5) and the lowest was in ghee (47.5 ± 3.2), whereas the lowest anisidine value was found in ghee (17.4 ± 1.0) and the highest in sesame oil (36.5 ± 2.2). Peroxide value was used to measure peroxide and hydroperoxide, whereas anisidine value determined secondary oxidation products, shown in Table 4 and Table 5 respectively. After the heat treatment of sesame oil, anisidine and peroxide values increased from low levels of 1.9 and 36.5 to 13 and 41 which equaled 84% and 11% changes respectively. The anisidine and peroxide values for soy oil increased from 5.7 and 19.1 to 31and 39, which equaled 81% and 52% changes respectively; whereas those of sunflower increased from 16.5 and 18.4 to 12 and 41, which equaled 41% and 55% changes respectively. The same trend was found in all the oils indicating that the main oxidative event was the formation of peroxide, followed by decomposition of peroxide leading to secondary oxidation.

The iodine value of each oil decreased during heat treatment and the saturation rate increased. The iodine value was from 120.9 to 35 in soy oil, which resulted in a 71% change; from 87.1 to 28 in sunflower oil, which equaled in a 68% change and from 104.8 to 79 in corn oil, which is a 24% change. Oxidation products were found to be unstable compounds, which might have undergone further reactions resulting in the formation of the flavor compounds such as aldehydes, ketones, alcohol, epoxides and hydrocarbons (Capuano et al., 2010, Friedman, 2003 and Mestdagh et al., 2008. Frying produced fatty acid oxidation products that reacted with asparagine and formed acrylamide. Table 5 showed that high concentrations of acrylamide were produced in soy oil (2447 ng/g) followed by palm olein (1442 ng/g), sunflower oil (1226 ng/g), sesame oil (1139 ng/g), olive oil (542 ng/g), corn oil (430 ng/g), lard (366 ng/g) and ghee (211 ng/g). The oils with high primary and secondary oxidant values exhibited higher acrylamide concentrations. When cooking oil was heated up to high temperatures, glycerol was degraded to acrolein (Stevens & Maier, 2008). Due to their high antioxidant contents, olive oil and sesame oil formed less acrylamide than the other oils; as acrylamide was formed by oxidation of acrolein to acrylic acid, which reacted with ammonium coming from nitrogen-containing compounds such as amino acids.

The formation of acrolein had been found to accelerate with increases in insaturation and polyunsaturated acids in the oil according to Uchida et al. (1999). The peroxidation of polyunsaturated fatty acids had been found to generate free acrolein and this was in agreement with the results presented in this study. It would be worthwhile to note that Mestdagh et al. (2005) reported that no significant difference in acrylamide formation was found between the various heating oils after frying French fries. Different frying methods and conditions could have been the cause of this disagreement; for they had used the tubular reactor at 175 °C for 2 min. Similarly, Mestdagh, Meulenaer, and Peteghem (2007) had investigated the oxidation and oil hydrolysis on the formation of acrylamide, and they had concluded that oil degradation products, such as glycerol, mono and diacylglycerols did not significantly influence the acrylamide formation. Totani, Yawata, Takada, and Moriya (2007) claimed that frying oil used in deep frying would not contaminate food stuffs with acrylamide. Both these studies used oxidized cooking oil, which might not have contained acrolein and acrylic acid and therefore acrylamide would not have been produced. Since the boiling points of acrolein and acrylic acid are 53 °C and 141 °C respectively, this would indicate that the compounds could be unstable and would easily be evaporated (Stevens & Maier, 2008). According to Selke and Frankel (1987) and Matthews, Scanlan, and Libbey (1971) the first products of hydrolyzed oil was glycerol and fatty acids, and acrolein was produced by the elimination of water from glycerol and oxidation of polyunsaturated fatty acids. Acrolein can also be produced as a result of the oxidation of polyunsaturated fatty acids and their degradation products (Matthews et al., 1971 and Selke and Frankel, 1987). Soy oil would be expected to be highly sensitive to oxidation because of the high content of unsaturated fatty acids; whilst some oils with high contents of saturated fatty acids, such as lard, might be expected to be less sensitive.

The dependence of the acrylamide content on oxidation was investigated by correlating the oxidation values presence with acrylamide amounts in different cooking oils, and a positive correlation was observed between peroxide value and acrylamide content ($R2 = 0.75$; $p < 0.05$). It would be noteworthy that both the iodine value and anisidine value correlated with the acrylamide content in cooking oil at ($R2 = 0.85$; $p < 0.05$), (Fig. 1). The anisidine and iodine values represented the levels of aldehydes and unsaturated double bonds respectively. Aldehydes had been found to be major degradation products in unsaturated oils due to their potential to exert toxicological effects, as they would react with the amino groups of proteins and produce acrylamide or aldehydes like acrolein, which would produce acrylamide (Umano and Shibamoto, 1987 and Yen and Wu, 2003).

5. Conclusion

The performance characteristics of the modified methods used in this study indicated that the methods were suitable for confirmatory analysis of acrylamide in cooking oils, as it was in compliance with AOAC (2002). The methods were confirmed suitable with certified reference material (CRM) of acrylamide in toasted bread. Unsaturated cooking oils produced high concentrations of acrylamide and high carbonyl compound content during heat processing. Correlations between the iodine values in the oils and animal fats and their acrylamide contents suggested that oils with more double bonds appeared to have higher acrylamide contents due to their unsaturated structures.

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