A Categorization of Runtime Norm Synthesis in Normative Multi-Agent Systems

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***Abstract*—Normative multi-agent systems are proving to be a promising approach in regulating open multi-agent systems. Normative rules created to regulate agent behaviour ideally should be created without the intervention of designers manually specifying each rule as norms are never constant. Norm synthesis is the process of designing agents able to generate and continuously refine said effective rules. The lack of categorization of runtime norm synthesis processes prompted this study to systemize the mapping of related architecture and frameworks, namely into norm detection, norm creation and norm revision aspect. This study aims to analyse the state of the art in norm synthesis approaches.**

Keywords—Normative Multi-Agent System, Norm Life cycles, Norm Synthesis, Norm Structure, Norm Revision, Norm Refinement.

I. INTRODUCTION

Normative multiagent systems (NMAS) as a research area can be defined as the intersection of normative systems and multiagent systems, where 'normative' mean 'conforming to or based on norms [1]. Originally built on deontic logics, normative multiagent research is a growing field in the design of adaptive autonomous agent architecture. Various frameworks, architectures and approaches has been developed since its conceptual inception [2]. Norms specify the standards of behaviours such as which actions or states should be achieved or avoided [3] by agents. Norms define patterns of behaviours by means of deontic modalities: *obligations*, which define which actions or states of affairs should be performed or satisfied by agents; and *prohibitions*, which define which actions or states of affairs should not be performed or achieved [4] and *permissive*; denotes states or actions that an agent has the choice to achieve or act. However, norms are never constant, terms such as *Norm Emergence*, *Norm Synthesis*, *Norm Creation*, *Norm Adaption, Norm Innovation* or *Norm Ideation* has been put forward to describe such phenomena. Normative rules created to regulate agent behaviour ideally should be created without the intervention of designers manually specifying each rule. Norm aware agents are able to create new norms, update or maintain norms and enforce norms [1]. Various works has been proposed to identify and categorize the major processes in order to make agents *norm aware,* furthermore *norm deliberative*. Norm synthesis can be described as rules that are not hard-coded recipes presenting reactive behaviours, such as those in the static expert systems, but rather describe consequences arising from observations for the purpose of reasoning about the current context, resulting in situation-specific norms [5]. Alternatively in an abstract state transition system, norm synthesis is the generation of rules for avoiding undesirable conflict states, leading to conflict-free states [6] and also aimed at developing stable set of norms [7].

This paper aims to explore the topic of Norm Synthesis; by categorizing and mapping processes as well as mechanisms used in which agents can identify, create, adopt and modify norms, with an emphasis of doing so at runtime without designers to specify norms manually (off-line or during design time) to produce expected agent behaviour.

II. NORM SYNTHESIS CATEGORIZATION

The concept of *Normative life cycle* [8][9][10] has been used to explain the mechanics (at a conceptual level) involved (or should involve) in making norm aware agents as shown in Fig.1. Norm synthesis is the problem of determining what is the set of norms that will effectively coordinate a normative multi-agent systems and encapsulates in which how norms can come to exist [11]. An analysis and summary comparison works of normative lifecycles can be referenced [12]. Other categorization approaches considered as non-cyclic agent processes can be shown in [2], where normative architectures are classified into several aspects which are; theoretical background, social embedding, philosophical background, norm concepts, norm dynamics and conflict detection, with several selected cases of known normative architecture as examples.

To relate our study with the formalization of normative lifecycle, our area of interest encapsulates the internalization and forget aspect both mentioned in [8] and [9] interpretation of a norm lifecycle, more specifically what approaches are norms modified and how to categorize such approaches.

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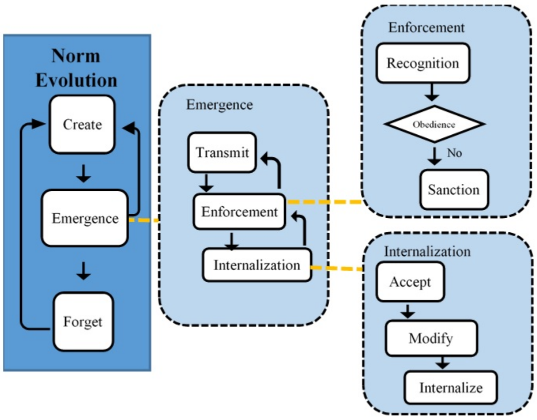

Fig 1: Norm Evolution [8]

The internalization process is the process which agent integrate new norms into their cognitive architecture (knowledge base) [13] also termed as norm immergence (internal emergence of norms) [14] [15]. Methods of norm internalization is seldom considered in the normative system literature [16]. The internalization process can be divided into Norm Acceptance, Norm Modification, and Norm Internalization as shown in Fig.1. The processes can be further defined as;

Norm acceptance is the process of conflict resolution in which external and external social enforcement compete against internal desire and motivations of the agent. Assumed as the follow-through process of norm acceptance or rejection deliberation. Once the cost of norm acceptance is viable the norms are integrated into the agent's knowledge base.

Norm transcription is the process of adding said norms into the agent knowledge base.

Norm reinforcement is the process of continually evaluating the accepted norm's relevance and the agents own compliance to said norms.

From the study of norm lifecycles, we propose a *norm synthesis classification framework* as shown in Fig.2. which would include a deeper categorization specifically on the aspects of norm transcription and reinforcement that was not addressed in previous works i.e. what knowledge formalism to use, expression of norms, support of non-monotonicity (i.e. revisions and modifications) consideration of said knowledge formalism on norms, structure etc. From this categorization framework, we categorized *runtime norm synthesis* related works into three (3) major aspects; *norm detection, norm creation, norm revision* and it's subdivisions in the following sections.

III. Norm Detection

Norm detection is the process of updating an agent's norms based on discovering a society's potential norms through some detection mechanisms. Other terms mentioned in the literature include norms recognition, norms adaptation and norm identification [9]. The detection or an occurrence of a conflict state can trigger a norm adoption. Accordingly, [2] concluded three types of conflict; between agents, between goals and norms and between norms. This study also applied the classifications proposed by [11] into norm detection, which can be broadly classified as exogenous or endogenous approaches in which implies the detection of norms are either externally or internally formalized (transcription into the agent's knowledge base).

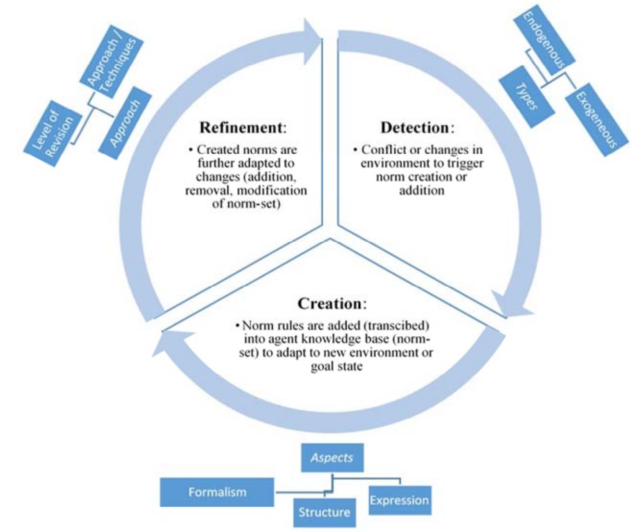

Fig 2: Norm synthesis classification

A. Endogeneous Norm Detection

Endogenous approaches require the agents to be endowed with computational capabilities to synthesise norms. This type of detection is also termed *Emergent (Bottom-Up)* approach of norm creation*;* Norms are recognized, created and deliberated by individual agents without the need of a norms managing entity, some call for methods of group voting of agreed upon norms and some use punishment and rewards (enforcement) to persuade agents to adopt or abandon certain norms. Several approaches were categorized in this work, noticeably;

Event Trace which represents actions, message exchanges or situations that has taken place during the execution of an agent or any other component of the simulation environment are recorded [4].

Social Learning agents learns from repeated interactions with other agents in a society and share their adopted norms (shared learning).

Illocution (declaration) of intention to other agents as a means to detect observable actions, or termed acts of speaking which in themselves effect or constitute the intended actions of agents [17].

B. Exogenous Norm Detection

Exogenous approaches are agnostic about norm internalisation and considers that norms are recognized by some regulatory entity, which may be an external regulatory mechanism, or even a group of regulatory agents i.e. **Electronic Institutions (EI)** or even **defined by the system designer.** We can relate this type of detection with *Prescriptive (Top-Down)* approach of norm creation*;* Norms are created, administered and regulated by a top-tier entity (or another agent or mechanism), where lower tier agents can only (in some cases) observe, adhere and report the norms to the managing entity.

IV. Norm Creation

Once a norm is detected either endogenously or exogenously, norms needed be registered or created within the normative system. In this study, norm creation pertains to the aspect of the norms being translated into a form able to be read, deliberated and modified by the agent.

A. Norm Representation

Norms must be presented in such a way that can be understood and processed by the agents [11]. Representation of norms in formalisms allows such generated norms to be manipulated (operationalized). According to [2] Norms representation can be categorized based on the theoretical background which are logic based, Belief-Desire-Intention (BDI) formalism and decision theory. In a different perspective [8][11] categorized based on the representation scheme which are modal logic further derived to deontic logic, rule-based systems, binary strings, and game theory.

From the literature we discern several types of formalism used in norm representation for runtime norm synthesis in broad terms of theoretical background of *knowledge representation* as either:

Logic Based representation models the agent's observation or state in logic formalisms, notably assigning deontic descriptors to said state and observation.

Rule Based representation models norms as attribute-object-value triples and the rules of plausible inference that connect them[18], i.e. if-then of norm condition and action (sanction or reward).

Game Theoretic / Decision Theory approach to norms are represented by the strategies that the agents use to make their decisions where an agent's decisions yield to a particular pay-off-matrix, with the aim of maximising its pay-off [11]. Also termed as decision theory, agents determine norms to follow based on utility [2].

B. Norm Structure

Norm structure pertains to the relation of generated norm rules (or rule-set) between other listed norms in the agent knowledge base. Broadly, **Linear** norm structure can be explained as being a list of norms generated without connection between other listed norms, while **Relational** norm structure denotes some form of relationship inter-norm wise. Various concept (or terms) of norm-set relationship has been described in the literature. *Normative Protocols* [10] has been described as order of the occurrence of events (protocols) associated with a norm [19]. A framework developed in [11] describe *Normative Network or relationship* as graph-based data structure to keep track of the norms that is explored during the synthesis process, whose nodes stand for norms and whose edges stand for relationships between norms where, a norm may have different states. *Norm Nets* is used [20] for modelling sets of interrelated regulations or norms, represented as either a single norm or a nested structure composed of norms connected by "and", "or" and "before" which in turn modelled into coloured petri nets.

C. Norm Expression

Norm expression relates to the type of norms being modelled. From the literature types of expressions of norms can be found as either; **State-Based** norm which refers to certain states that should be achieved or avoided, concerning a state of system organization while action-based or **Event-Based** norm refers to certain actions that should be performed or avoided at the level if the actions of participants [3] [21]. Also termed as *conditional expression* to represent condition that activates the norm and the norm deactivation situation [17]. In a sense, norm expression is considered as the format or what the norms are being represented as.

V. Norm Revision / Refinement

Norms within a system naturally changes. Current adopted, popular or beneficial norms may not apply to current situations, or current adopted norms may be replaced with more suitable norms, be it due to not just utility of such adopted norms (effectiveness) but can be in terms of deliberativeness or compactness of the discovered norm-set [11]. Norm revision approaches are typically motivated by the following issues: [22] Norms are conflicting and thus agents are unable to comply with them, secondly some desirable state is rarely achieved, which indicates that there is insufficient guidance for agents, finally some undesirable state is frequently visited, which indicates that agents prefer to take the course of action leading to that state, the penalty notwithstanding. We can also perhaps relate that norm refinement is similar to norm deliberation, however deliberation only postulate the viability for adopting norms for example in terms utility of said norms but however does not explain how such an adoption will modify the new or existing agent norms (knowledge of norms), or how the structure of said norm-sets be modified and to what extent.

A. Norm Refinement Approaches / Techniques

Several approaches and techniques were clearly stated in some related works. Some of those approaches can be categorized into:

Rule set manipulation (RSM) is the modification of norm-set through the addition and removal of norms internally or externally processed commonly using utility of the detected norm or a certain defined threshold value. We assume any works that applies the modification of norm sets without any specific approaches as generally termed as rule set manipulation.

Group consensus (GC) / Argumentation (Arg) is categorized as approaches for changing of norms by agents considering, proposing, arguing and adopting agreed upon norms. Applied in simulations for collective / social learning to norm adoption i.e. policy voting and argumentation between other agents.

Inductive logic programming (ILP) is a machine learning technique concerned with the induction of logic theories that generalise (positive and negative) examples with respect to a prior background knowledge [22]. Used in conjunction with Answer Set Programming (ASP).

Evolutionary mechanism (EM) uses the principles of biological evolution (such as reproduction, mutation, recombination, and selection) to solve problems on computers [23]. For example; a population of candidate norms is created and evaluated on a simulated system. The best performing candidates are reproduced, using evolutionary algorithm techniques, into the next generation and re-evaluated. This process continues until an adequately effective norm is found [24].

Reinforcement Learning (RL) is a computational approach to understanding and automating goal-directed learning and decision making. It can be termed as trial-and-error approach to interactions with its environment to discover the best utility function [25] in this case the most efficient norms to detect or generate and adopt.

B. Levels of Norm Refinement

From our perspective norms refinement can be divided into several level of refinement in terms of how extensive the operations on the generated norms are. We identify several levels (4); Norm refinement through the **addition (activation) and removal (deactivation) of detected norms in a set of norms (L1)**, which are commonly stored and sorted as lists and iterated when agents deliberate on its action and goal. Secondly, norm refinement can also encompass the **modification of the connection or relationship between detected norms (L2)** should the norms be structured**.** Third, the **modification of the norms syntax (L3)** itself in which new norms are synthesized from modification of existing norms. Finally, the adopted set of **norm weights and value are modified (LW)** as the norms are continuously evaluated when the agent interacts in the simulation environment i.e. in terms of norm relevance, utility, ordering.

VI. Mapping And Discussion

From the *Norm Synthesis Aspects* as previous discussed, we have categorized several runtime norm synthesis related framework and approaches. The summary can be shown in Table.1. Notably Logic Based norm representation seems to be the most flexible in terms of application in modification of norms (**L1, L2, L3**) however lacking in being able to assign valuation to the degree of utility of generated norms (**LW**) compared to Game theoretic / Decision theory approach but lacking in most refinement of syntax, structure and norm set manipulation. Relational norm generation and refinement seems lacking in terms of runtime norm synthesis even though several approaches have been proposed as previously mentioned (Section 4: Norm Structure). Fig.3. Shows the mapping in bubble chart form. This study was expecting Reinforcement Learning to be the dominant mechanism for norm refinement due to the purpose of reinforcement learning is to explore and exploit the agent's environment and determine the best state or action to maximize utility, while the addition of norms can attribute to the pruning of certain obligative or prohibitive actions. Our future study should focus on this issue.

From the mappings we can postulate that; Norm detection seems to favor the endogenous approach (68%-Endogenous and 32%-Exogenous) implementation, not to say endogenous is better than exogenous but the focus seems to be the design of individual agents with standalone norm aware and deliberative qualities. Secondly the adherence towards symbolic (rule and logic based) school of knowledge representation and reasoning is quite dominant (Logic-based – 56%, Rule-based-28%, Game theory-17%), justifiably the mentioned approach is more descriptive, declarative and expansive in norm memory retention than say a fixed payoff matrix utility function of action or state, however more complex in its implementation. Representation of complex relational norm structure seems to be lacking (Linear-65%, Relational-35%) and seems to be a good area for further study into what type of inter-norm-connection is implemented. Finally the level of norm refinement seems lacking for complex operation into modifying the inter-norm relations, norm syntax and dynamic norm values (L1-50%, L2-19%, L3-12%, LW-19%), and we should focus our future study in this area also.

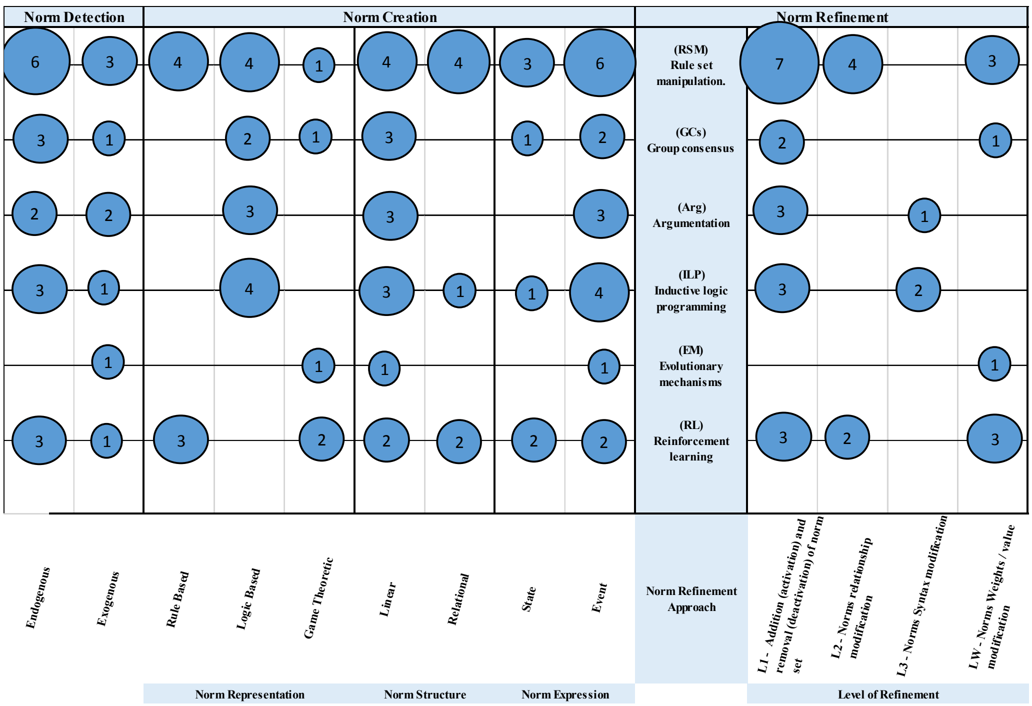

Fig 3: Bubble-chart of Norm refinement approaches in relation to norm synthesis aspects

TABLE 1: MAPPING OF WORKS IN NORM SYNTHESIS

	Norm Detection		**Norm Creation**			**Norm Refinement**				
Reference	***Endogenous***	***Exogenous***	***Norm Representation***	***Norm Structure***	***Norm Expression***	***Approach***	***Level of Refinement***			
Alrawagfeh, W. [26][27][28]	Social Learning, Event Trace		Logic Based	Linear	Event	GCs, RSM	L1			
Artikis, A. [29][30]	Social Learning	Designer Defined	Logic Based	Linear	Event	GCs, Arg	L1			
Athakravi, D. [31]		Designer Defined, Event Trace	Logic Based	Linear	Event	ILP, Arg	L1			
Bou, E. [32]		Electronic Institution	Game Theory	Linear	Event	EM				LW
Christelis, G. [6][33]	Event Trace		Logic Based	Relational	State	RSM	L1	L2		
Corapi, D. [22]	Event Trace		Logic Based	Linear	Event	ILP	L1		L3	
Criado, N. [4]	Event Trace		Rule Based	Linear	State and Event	RSM	L1			
EMIL* [34][35][36]	Event Trace		Game Theory, Rule Based	Linear	Event	RSM, RL	L1			LW
Frantz, C.K. [37]	Event Trace		Rule Based	Relational	Event	RL	L1	L2		
King, T.C. [38][39]	Event Trace		Logic Based	Relational	State and Event	ILP			L3	
Lee, J.H. [5]	Event Trace	Designer Defined	Logic Based	Linear	Event	RSM	L1	L2		
Li, T. [40]	Event Trace		Logic Based	Linear	Event	ILP	L1			
Liao, B. [41]	Event Trace		Logic Based	Linear	Event	Arg	L1		L3	
Meneguzzi, F.R. [42][16]		Designer Defined	Logic Based	Relational	Event	RSM		L2		
Morales, J. [7]		Electronic Institution, Event Trace	Rule Based	Relational	State	RSM, RL	L1	L2		LW
Riveret, R. [43]	Social Learning		Game Theory	Linear	State	RL, GCs				LW
Vasconcelos,W.W. [44]	Illocution		Rule Based	Relational	Event	RSM	L1			LW

*EMIL frameworks considered as a collection of approaches with varying modifications to its main architecture (EMIL-A) by different researchers

**Norm Refinement Approach*

RSM – Rule set manipulation
GCs – Group consensus
Arg – Argumentation
ILP – Inductive logic programming
EM – Evolutionary mechanisms
RL – Reinforcement Learning

**Level of Refinement*

L1 - Addition and removal of norm set
L2 - Norms relationship modification
L3 - Norms Syntax modification
LW - Norms Weights / value modification

VII. CONCLUSION

This paper has presented an approach to categorize norm synthesis related works into three (3) aspects namely; *Norm Detection, Norm Creation* and *Norm Revision* derived from several previous categorization works. The mapping of several related works has shown some areas lacking in *Runtime Norm Synthesis*, specifically in the generation of effective normative rules with relational norm structure and normative rules revision beyond only addition and removal of adopted norms.

As further works, we intend to address the issue as previously mentioned by proposing a technique for runtime synthesis of relational structured norms and expand the categorization further and include more related literature including well known normative architectures for a more thorough in-depth analysis.

VIII. ACKNOWLEDGEMENT

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