A Boltzmann Machine For Solving Time Tabling Problem

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ABSTRACT

A neural network approach for solving the time tabling problem is presented. A Boltzmann machine neural network based system is developed for finding optimal faculty schedule. The system first formulate the problem of time tabling in a graph form and the optimal scheduling problem is considered as a graph coloring problem. Several educational systems schedules are considered.

ماكنة بولتزمان لحل مشكلة الجدولة الزمنية

ملخص

تعرض الورقة لتوجه مبني على الشبكات العصيبية لحل مشكلة الجدولة الزمنية. عرض لمنظومة تستند إلى ماكنة بولتزمان لإيجاد جدولة مثالية لنظم أكاديمية مختارة. يقوم النظام بتمثيل مشكلة الجدولة في هيئة مخطط ثم يحل مشكلة الجدولة بتحويرها الى مشكلة تلوين المخطط. ثم حلها من خلال إيجاد الحل الامثل لمشكلة تلوين المخطط. تعرض الورقة لحلول مشاكل جدولة زمنية لعدد من النظم التعليمية الجامعية المختارة.

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1. Introduction

Many contributions related to time tabling have appeared and it will probably continue with the same rate for years. One reason for this may be the huge variety of problems which are included in the field of time tabling; another reason is the fact that educational methods are changing so that the models have to be modified [1]. Usually one considers the time tabling process that consists of two distinct phases:

a) The curricula are defined for each class or for each group of students and one has to assign the various resources to the classes.
b) When an agreement has been reached concerning these assignments of resources, then one tries to see whether a workable detailed timetable can be worked out which is compatible with all the previously defined requirements, and this phase is generally handled by the computer [1,2].

The increase in the number of students and departments in faculties in universities necessitates the use of the computer as a means to finding a solution to the scheduling problem. A computer solution gives reliable results, while permitting flexibility and saving human effort. Various types of computer solutions for solving the scheduling problem were offered by different researchers starting from the early sixties when Almond [3] used a heuristic method to construct a timetable for one department in which courses for each class were fixed, however Almond's method did not consider the desired time for giving lectures, availability of lectures and their requests also it puts the program in unclosed loop because a course may be inserted in the period for a fixed course. These points are taken into consideration in the method developed by S.M. Selim[2,4] which is a modification of Almond's method where the fixed time courses are listed at the top followed by the multiple-period courses and then single-period courses. D.de.Werra [1] developed an algorithm for solving time tabling problem based on vertex coloring. The graph theoretical model used associates each lecture of each course a lecture-vertex node; edges between all pairs of lecture-vertices exist whenever there is a student takes the two courses.

Colorni [5] considered the problem of high school time tabling with reduced constraints and proposed a solution based on genetic algorithm. A good survey of automated timetabling is given by . Schaerf [6].

Most time tabling problems which were discussed up to now have been formulated as feasibility problems (*find a feasible solution*) rather than optimality problems (*find an optimal solution*) since no distant objective function can be defined. In fact both formulations are very similar since finding a feasible solution may be regarded as minimizing a kind of distance to feasibility. Even those tried to solve the time

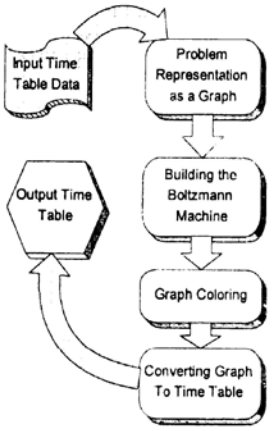

Figure 1: The BMTT System

tabling problem as an optimality problem failed to come up with solutions that take reasonable time with reasonable computation complexity. The problem is an NP-complete problem and its complexity highly increases as the number of courses and constraints increases.

In this paper a system is presented for solving the time table system using Boltzmann machine neural network. The developed method for solving the problem is based on formulating the time tabling problem -in hand- as a graph coloring problem and then solving the graph coloring problem using the BMGC system developed by the authors and presented in [7]. The Boltzmann Machine Time Tabling (BMTT) system presented in this paper is a modification of the BMGC system presented in [7]. Different educational systems with different types of time tabling are considered in the following sections.

2. Boltzmann Machine(BM)

Boltzmann machine is one of the most recently introduced models in the field of neural computing. Boltzmann machine combines interesting properties from both neural computing and simulated annealing, resulting in a powerful computational model exploiting massive parallelism in a natural way [7-9].

Boltzmann machine was introduced by Hinton & Sejnowski (1983), this connectionist model can be viewed as a generalization of Hopfields content addressable memory. However the basic idea underlying this neural network model, i.e. the implementation of local constraints as connection strengths in stochastic network, was introduced by Moussouris [10], these local constraints can be considered as a quantitative measure of the desirability that the units joined by the connections are both *ON*. The units in a Boltzmann machine try to reach a maximal consensus about their individual states subject to the desirability expressed by the connection strengths. To adjust the states of the individual units to the states of their neighbors a probabilistic (stochastic) state transition mechanism is used [7,10,11].

3. The BMTT System

The developed/implemented Boltzmann Machine for solving Time Tabling problem (BMTT) system consists of the stages shown in figure 1. The input to the BMTT system is the information required for constructing the time table in addition to the constraints, according to the educational system considered.

Once the required information is input then a graph model of the time tabling problem -in hand- is constructed by the system in the graph representation phase. This graph is to be colored in later stages by the BMGC system. In the graph representation stage several conditions must be satisfied; the number of links must not exceed the total number of vertices and each vertex can not have a loop connection. The graph is then represented by a two dimensional matrix called the ' *conflict matrix* '(CM) calculated as in equation (1);

$$CM_{ij} = \begin{cases} 1 & \text{if i \& j are adjacent} \\ 0 & \text{otherwise} \end{cases} \quad \ldots(1)$$

The system then builds a suitable Boltzmann machine for the given graph as in [7].

The BMTT system outputs the optimal time table for the problem considered plus the following optional output; a sketch of the graph representing the time tabling problem considered, a table of vertices colors obtained from coloring the graph, and the Boltzmann machine network constructed by the system.

4. Implementation and Results

The BMTT system was implemented on four types of time tabling (scheduling) problems related to three educational systems applied in Iraq; these are;

1. Full Year Course Scheduling (FYCS).
2. Modified Full Year Scheduling (MFYCS).
3. Semester Scheduling (SS).
4. Final Examination Scheduling (FES).

The Full Year Course Scheduling (FYCS) is applied in almost all Iraqi educational institutions including University of Baghdad, University of Technology and others. The full year courses are fixed for all students. In Modified Full Year Course Scheduling (MFYCS) the full year courses are fixed too, but with some additional constraint that a student who fails in a certain subject(s) can pass to the next year but he should attend the subject(s) he failed in. The MFYCS was applied in Iraqi universities (loading scheme), it is still applied in Saddam University for each quarter and not a full year.

Another different system that is used by some colleges of Al-Mustansiriya University is Semester Scheduling (SS) where each student determines his own options according to a specific set of courses. Finally; Final Examination Scheduling (FES) -which is necessary for every educational institution- is considered.

4.1 Full Year Course Scheduling (FYCS)

Problem Definition

Year	Professor	Course title	Hours	Consecutive(y/n)
1	A	AA	1	n
	B	BB	1	n
	C	CC	1	n
Number of Classes = 1				
2	A	AA2	1	n
	E	EE	1	n
	F	FF	1	n
Number Of Classes = 1				
3	B	BB2	1	n
	E	EE2	1	n
	D	DD	1	n
Number of Classes = 2				
4	A	AA3	1	n
4	G	GG	2	y
Number of Classes = 1				
Fixed Courses, that hold at a specific time: G must hold in Sunday				

Table 1: System Input; Full Year Course Schedule Data

The problem is to construct a timetable for each professor and class that satisfies the teaching requirements and obeys the essential restriction that no lecturer or class is to be present at two places at one time. Courses with two or more consecutive hours, and the ability of restricting the schedule of certain courses or professors are to be considered. The time table is to be optimized in the sense that the lectures are distributed on minimum number of working (hours) days.

Test example

An example of such FYCS problem for a four year study in one department is given in table 1. Data required to be entered to the BMTT system should contain; the number of study years, courses for each year, name of professors that deliver these courses, number of weekly lectures of each course and whether some are consecutive, number of classes per each year, and lectures or professors that have restricted lecture schedule; as in table 1.

The graph representation phase uses the FYCS problem system input. Each graph vertex denotes a specific attribute; year number, class number and professor name. An edge between two vertices exists if and only if their attributes overlap. Table 2 and Figure 2 show the BMTT system output of the graph model of the FYCS problem considered in table1. As can be seen; a graph made of fifteen vertices is constructed, each vertex has no more than four connections.

Year	Class	Prof.	Vertex Number	Number of Connections	Connected to
1	1	A	1	4	2,3,4,13
1	1	B	2	4	1,3,7,10
1	1	C	3	2	1,2
2	1	A	4	4	1,5,6,13
2	1	E	5	4	4,6,8,11
2	1	F	6	2	4,5
3	1	B	7	4	2,8,9,10
3	1	E	8	4	5,7,9,11
3	1	D	9	3	7,8,12
3	2	B	10	4	2,7,11,12
3	2	E	11	4	5,8,10,12
3	2	D	12	3	10,11,9
4	1	A	13	4	1,4,14,15
4	1	G	14	2	13,15
4	1	G	15	2	13,14

Table 2: System Output; Graph Model Data

The constructed graph is colored in the graph coloring stage through the use of Parailel/ Synchronous/ Unlimited (PSU) mode of operation [7] which is modified to include some additional constraints that are;

1. The lecture with constrained time is to be determined first, then it is considered as the initial Boltzmann machine configuration .
2. In case of lectures with consecutive time periods; the number of Boltzmann machine layers is the number of periods of time used to construct the timetable, i.e. each hour in a certain day represents a specific Boltzmann machine layer.

The output of the graph coloring stage is mapped to denote the vertices by the attributes they represent while the color value is replaced by the time value it represents. Table 3 shows the results obtained from the BMTT system for scheduling the FYCS problem given in table 1. Each vertex in the colored graph is replaced by the year, professor and class it stands for then the color value is changed by the day and hour corresponding to it.

From table 3 it is clear that if the working hours per day are from 8 to 11 then only one working day plus one hour from another day are sufficient to schedule the lectures given in table 1 without overlapping.

4.2 Modified Full Year Course Scheduling(MFYCS)

Problem Definition

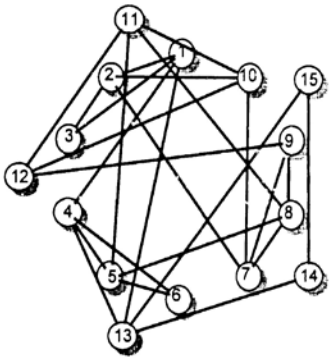

Figure 2: System Output; Sketch of Graph Representing the Problem of Table 1.

Day	*Time*	*Year*	*Class*	*Professor*
Sunday	10-11	1	1	A
Sunday	9-10	1	1	B
Sunday	8-9	1	1	C
Sunday	8-9	2	1	A
Sunday	10-11	2	1	E
Sunday	9-10	2	1	F
Sunday	8-9	3	1	B
Sunday	10-11	3	2	B
Sunday	9-10	3	1	E
Sunday	8-9	3	2	E
Sunday	10-11	3	1	D
Sunday	9-10	3	2	D
Monday	8-9	4	1	A
Sunday	8-9	4	1	G
Sunday	9-10	4	1	G

Table 3: System Output; Full Year Course Schedule.

In MFYCS, if any student fails in a subject(s), he is permitted to pass to the next year, but he must attend the lectures of the subject(s) he failed in, the past year.

❁ ***Test example***

Table 4 represents an example of MFYCS problem. Figure 2 is the BMTT output of the graph representation. It can be seen from table 5 that the system was able to give a nonconflecting time table covering only four lecture periods (hours) assuming there is no problem in class rooms. However, if there is problem with class rooms; number of class rooms can be entered as input to the system to be considered as a constraint.

4.3 Semester Scheduling

❁ ***Problem Definition***

Year	*Professor*	*Course*	*Hours*	*Consecutive(y/n)*
1	A	AA	1	n
	B	BB	1	n
2	C	CC	1	n
	B	BB2	1	n
	E	EE2	1	n
	F	FF2	1	n
Are there any subjects from previous year? (y/n)				y
1	B	BB	1	n
3	A	AA3	1	n
	E	EE3	1	n
	D	DD	1	n
Are there any subjects from previous year? (y/n)				y
2	F	FF2	1	n
4	A	AA3	1	n
	G	GG	2	y
Are there any subjects from previous year? (y/n)				n

Table 4: System Input; Modified Full Year Course Schedule Data

In some universities and faculties, students wishing to study a particular subject find that all the subjects to be studied in a given year are determined and that there is very little choice. In other universities, there are few conditions and students have a great deal of choice. In many cases the reason behind these conditions is the difficulty of constructing a timetable according to students selection of courses with no conflicts or overlaps.

❁ ***Test example***

A simple SS problem is considered in table 6. Both courses and students choices are given in table 6. The graph representing the problem is drawn in figure 4. The output schedule is given in table 7.

4.4 Final Examination Schedule(FES)

❁ ***Problem Definition***

Scheduling of final examinations at universities or similar institutions is a tedious and frustrating task. The Coordinator must assign courses to blocks of exam periods which yield a minimum number of conflicts. Under normal circumstances, lacking a more formal procedure the Coordinator uses experiences combined with intuition to choose an exam schedule. He then proceeds to check the schedule for conflicts in each students program. If he has the resources he may repeat the procedure, varying the schedule in an attempt to reduce the number of conflicts.

❁ ***Test example***

Table 8 gives an example of a second attempt final exam; each student must attend number of exams according to his exam results in the first attempt. It is required to come up with a time table with minimum number of days. One exam in each day is to be conducted. Result of exam scheduling is shown in table

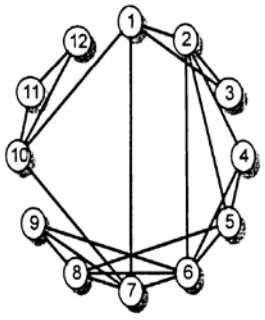

Figure 3: System Output; Sketch of Graph Representing the MFYCS Problem of Table 4.

Day	Time	Year	Professor
Sunday	9-10	1	A
Sunday	10-11	1	B
Sunday	8-9	1	C
Sunday	9-10	2	B
Sunday	8-9	2	E
Monday	8-9	2	F
Sunday	10-11	3	A
Sunday	9-10	3	E
Sunday	8-9	3	D
Sunday	8-9	4	A
Sunday	10-11	4	G
Sunday	9-10	4	G

Table 5: System Output; Modified Full Year Course Schedule.

9. The graph representing the problem is given in figure 5.

5. Conclusion

Boltzmann machine is a feedback multi-layer network where one puts the input values in the network neuron then one carries out four ingredients: concise description of a configuration of the system through which the state of each unit is determined after each trial of the optimization process; a random generator of ' moves ' i.e. specifying the unit that may or may not change its state; a quantitative objective function containing the trade-off that have to be made; and a cooling schedule of the temperatures and length of times for which the system is to be evolved. The cooling schedule may be developed by trial and error for a given problem, or may consist of just warming the system then cooling in slow stages until diffusion of the components ceases.

Professor	Course Title	Hour	Consecutive(y/n)
A	AA	2	y
B	BB	1	n
C	CC	1	n
D	DD	1	n
E	EE	1	n
F	FF	1	n
No Fixed Courses			

(a) Courses to be scheduled

Student Number	Professor Name	Course Title
1	A	AA
	B	BB
	C	CC
2	C	CC
	E	EE
	F	FF
3	B	BB
	D	DD
	F	FF

(b) Students Choices

Table 6: System Input; Semester Schedule Data

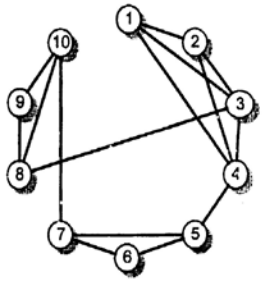

Figure 4: System Output; Sketch of Graph Representing the SS Problem of Table 6.

Time tabling is an interesting field of research. In this paper the time tabling problem was formulated as a graph coloring problem. Optimal scheduling (time tabling) is obtained from the developed /implemented BMTT system through different system stages. A graphical model for the given time tabling problem is first constructed, graph vertices represent problem attributes. The existence of an edge between two vertices is based on the existence of common attributes. A proper Boltzmann machine neural network is designed by the system to optimally color the graph, then the colored graph is converted into a time table by converting each vertex into its features or attributes and each color to the corresponding time period.

In BMTT system maximizing the consensus function of the Boltzmann machine equivalent to solving the graph coloring problem where the best or optimal solution among a finite number of alternative solutions, is selected based on a quantifiable measure that

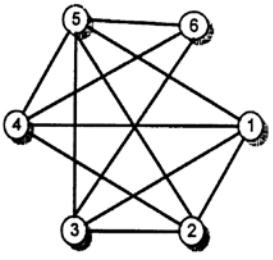

Figure 5: System Output; Sketch of Graph Representing the FES Problem of Table 8.

Day	Time	Professor	Course	Student
Sunday	8-9	A	AA	1
Sunday	10-11	A	AA	1
Sunday	9-10	B	BB	1,3
Monday	8-9	C	CC	1,2
Sunday	8-9	D	DD	3
Sunday	8-9	E	EE	2
Sunday	10-11	F	FF	2,3

Table 7: System Output; Semester Schedule.

distinguish one solution from another i.e. the consensus function.

The time taken by the BMTT system for finding the optimal solution of any time tabling problem is problem dependent; yet it can not be compared to any other conventional method. Solving the time tabling problems reported in this paper took execution times measured in few milliseconds on a 486 PC. Any constraints other than those demonstrated in this paper can easily be incorporated to the system. The system is

The Subjects Are A,B,C,D,E,F	
Student Number	Student Subjects
1	C,E,F
2	E,B,A
3	B,A,C
4	D,E,F
5	D,A,B

Table 8: System Input; Final Exam Data

Subject	Day of Exam
A	Monday
B	Tuesday
C	Sunday
D	Sunday
E	Wednesday
F	Monday

Table 9: System Output; Final Exam Schedule.

expected to be very helpful and useful for educational institutions.

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Agreement Rules In Arabic: A Minimalist Approach

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ABSTRACT

The objectives of this study are both descriptive and theoretical within the mainstream of the current syntactic theory, namely, Chomsky's (1995) Minimalist Program. This study attempts to formulate an articulated structure of Agr and explore configurational and categorical accounts of Subj. – predicate and V- subj. insofar Ø- agreement features are concerned. The article deals with Agr as a strong functional category in the former because the agreement features are drawn from the lexicon and have the [+interpretable] power at LF. However, in the latter structure, Agr is weak and is eliminated from the lexicon, as it does not have visible interpretable features to be checked in the output of the same level. We will argue that Agr is as essential as T since Agr does the function of Ø- feature as well as case checking. DP agreement features are drawn from the lexicon for emphasis and are not liable for checking by P.

قوانين المطابقة في اللغة العربية: المنهج التطبيقي

ملخص

يشتمل هذا البحث على دراسة وصفية- تنظيرية لبعض التراكيب والعناصر اللغوية ضمن إطار النظرية النحوية كما قدمها تشومسكي في كتابة المنهج التخفيضي 1995 والأبحاث المشابهة. الهدف الرئيسي من هذه الدراسة هو تحليل الصنف الوظيفي المعروف بالمطابقة إلى عناصر وظيفية مستقلة كانت تعدّ في الدراسات السابقة خصائص مدونة في الفعل أو الخبر ولا يمكن فصلها عنهما ,تم استطلاع عناصر المطابقة على أنها ذات نوعين ,إذا بدأت الجملة بمبتدأ ثم تبعة الخبر كانت المطابقة ذات عناصر قوية تنفصل عن عناصر المطابقة الملتصقة بالفاعل لأنها تجبر الخبر على تفحص تلك العناصر ,أما إذا سبق الفعل الفاعل كانت المطابقة ضعيفة وجاز حذفها من السياق لعدم وجودها، أما عناصر المطابقة الأخرى الملتصقة في الفاعل فهي جزء منه في البنية ولا تنتمي إلى مصنف المطابقة.

تاريخ تسلم البحث: 2002/5/2 تاريخ قبول البحث: 2003/10/8

AGREEMENT RULES IN ARABIC: A MINIMALIST APPROACH

1. ANALYSIS OF AGREEMENT IN ARABIC: DESCRIPTIVE APPROACH

Preliminary

The agreement between the subject and the verb in Modern Standard Arabic is entirely deferential to the linear order of the two elements in a sentence. Arabic is treated as VSO in the work of Traditional Arab Grammarians and in the recent work of generative grammar as in Sa'ad (1984). However, in the current theory of generative grammar, it is dealt with as SVO at spell-out (see Mohammed (1989), Fasi Fehri (1989),Aoun (1994) and Jalabneh (1992, 1996).

The objectives of this study are both descriptive and theoretical within the mainstream of current syntactic theory, namely, Chomsky's (1995) Minimalist Program. The study attempts to formulate an articulated structure of Agr and explore configurational and categorical accounts of Subj.-predicate and Predicate- subj. with regard to Ø - agreement features in Arabic syntax. The article deals with Agr as a strong functional element whenever the predicate is an Adj, DP or V as it drawn from the lexicon and carries the [+interpretable] feature. However, Agr is weak whenever the predicate V precedes the subject DP; it is eliminated from the lexicon, as it is not visible in the output of LF.

1.1 The Function of Agr in the Configuration [Subj.- predicate][(1)]
AgrP

If the predicate is a verb, adjective or noun, it agrees in number, person and gender with the pre-verbal noun phrase. We may look at the specimen (1) in which the predicate is the verb 'najah' *passed* and explain the function of Agr rules in this order.

1a.	al	-	ṭālib	- u	najaḥa	-Ø	fi	al	-?imtiḥān	– i
	DET		student	NOM	passed	3rd,sg,masc.	in	DET	exam	LOC

'The student passed the exam.'

1b.	al	- ṭalib	-āni	najaḥ	- ā	
	DET	student	two NOM	passed	DL. masc.	
	fi	al -	?imtiḥan	-i		
	in	DET	exam	LOC		

'The two students passed the exam.'

1c. al - tullāb -u najaḥ - u
DET students NOM passed 3rd,pl.masc.
fi al - ? imtiḥān - i
in DET exam LOC

'The students passed the exam.'

(1a) indicates that the verb 'najaḥa' *passed* is 3rd person singular masculine, and it agrees with the subject 'al- ṭālibu' *the student* : In (1b) the verb carries the dual masculine marker a and agrees with the dual subject 'al-ṭalibāni' *the two students*. In (1c) the plural marker u is added to the verb 'najaḥ' *passed* to agree with the subject 'al-tullābu' *the students*.

If the subject of the sentence is feminine, the respective feminine marker also marks the verb. We may look at (2) to illustrate the point.

2a. al- ṭālib -at - u najaḥ - at
DET student fem NOM passed 3rd,sg,fem .
fi al - ?imtiḥān – i
in DET exam LOC

'The female student passed the exam.'

2b. al - ṭalib -at -āni najaḥ -atā
DET students fem two NOM passed fem DL. marker
fi al - ?imtiḥān - i
in DET exam LOC

'The two female students passed the exam.'

2c. al - ṭālib - āt -u najaḥ - na
DET students fem NOM passed PL,fem
fi al – ?imtihan - i
in DET exam LOC

'The female students passed the exam'.

*2d al - ṭālib - at -u najaḥ -a
DET student fem NOM passed 3rd, sg,masc
fi al - ?imtiḥān - i
in DET exam LOC
'The female student passed the exam'.

(2a) indicates that the verb 'najaḥa' *passed* is marked by the 3rd person singular feminine marker *at*. In (2b) the feminine marker at and the dual marker atā are added to the verb to indicate the agreement. In (2c) the verb is marked by the feminine plural marker na for the same purpose. (1) and (2) illustrate that in SVO order, the predicate has to agree in number, person and gender with the subject (2d) is

ungrammatical since the verb 'najaḥa' does not agree with the subject 'al-ṭālibatu' in gender.

However, this rule of agreement is not uniformly met. In case the subject is [- human] plural and masculine as in 'al-qiṭaṭu' *male cats* or plural and feminine as in 'al-hiraru' *female cats*, the verb is always 3rd person, singular feminine as in (3) and (4) respectively.

3.	al-	qiṭaṭ	-u	ṣaᶜid	-at	al-	sullam	-a
	DET	cats	NOM	climbed	3rd,sg,fem	DET	ladder	ACC

'The cats climbed the ladder.'

4.	al -	hirar	- u	harab	-at
	DET	cats fem	NOM	ran away	fem,sg.

'The cats ran away.'

If the verbs in (3) and (4) are made 'ṣaᶜidu', 3rd masculine plural and 'harabna', 3rd plural feminine respectively, the sentences will be ungrammatical.

Another violation to the set of rules in subj.- predicate order is that if the subject is [- animate] and singular or dual, the predicate 'hutim' be *destroyed* agrees with it in all features as in the specimen (5a). However, if the subject is [- animate] but plural masculine, the verb is 'hutimna' *were destroyed* which is 3rd plural feminine as in (5b) or 'hutimat' 3rd singular feminine as in (5c) respectively.

5a.	al -	ṣnām	-u	ḥuṭim	- Ø
	DET	statue	NOM	was destroyed	3rd,sg, masc.

'The statues was destroyed'

5b.	al -	?aṣnām	-u	ḥuṭim	-na
	DET	statues	NOM	were destroyed	pl,fem

'The statues were destroyed'

5c.	al -	?aṣnām	-u	ḥuṭim	-at
	DET	statues	NOM	were destroyed	sg,fem

'The statues were destroyed'

In coordinated constructions, if the conjoined NPs have the same gender, the verb will also have the same as in (6a). However, if the conjoined NPs are different in genders, the verb is always masculine and agrees with it in number and person as in (6b) and (7) respectively.

6a.	zaid	-un	wa	ᶜamr	-un	?akal	-ā	al	-tufaḥat	-a
	Zaid	NOM	and	Amr	NOM	ate	DL,masc.	DET	apple	ACC.

'Zaid and Amr ate the apple.'

6b. zaid -un wa hind -un ?akal -ā al -tufāḥat -a
Zaid NOM and Hind NOM ate DL,masc. DET apple ACC.

'Zaid and Hind ate the apple.'

7. hind -un wa faṭimat -u wa maryam -u wa
Hind NOM and Fatima NOM and Maryam NOM
zaid -un ?akal -u al - tufāḥat -a
Zaid NOM ate PL. masc DET apple ACC

' Hind , Fatima, Maryam and Zaid ate the apple.'

In short, if the subject is [+human] whether singular, dual or plural, the verb agrees with it in all agreement features. In addition, if it is [-human] or [-animate] singular or dual the verb is treated as in animate subject. However, if it is [- human] or [-animate] plural masculine or feminine, the verb is 3rd singular and feminine. In coordinated constructions, the masculine but not the feminine gender is prominent whenever the gender varies.

1.2 The Function of Agr in the Configuration [V, NP].
Agrs

The form of agreement between the subject and the V-predicate is entirely different. The verb is always 3rd person singular but agrees in gender with its post-verbal subject. (8) is a specimen of this type.

8a. kataba - Ø al - tilmīḏ - u al - dars -a
wrote 3rd, sg, masc. DET student NOM DET lesson ACC

'The student wrote the lesson.'

8b. kataba - Ø al- tilmīḏ - āni al- dars -a
wrote 3rd, sg, masc. DET student DL, NOM DET lesson ACC

'The two students wrote the lesson.'

8c. kataba - Ø al - talamīḏ - u al- dars -a

wrote 3rd, sg, masc. DET student PL, NOM DET lesson ACC

'The students wrote the lesson.'

8d *katab - a al - tilmīḏ - āni al- dars -a
wrote DL, masc. DET boys two NOM DET lesson ACC

'The two boys wrote the lesson.'

In (8a,b&c), the verb 'kataba' *wrote* is 3rd, person, singular and masculine. It only agrees in gender with the subjects 'al-tilmidu' *the student*, 'al-tilmidani' *the two students* and 'al-talamidu' *the students* respectively. However, (8d) is ill – formed, as the verb 'kataba' *both wrote* cannot match the subject 'al-tilmidani' *the two students* in all Ø- agreement features.

This rule of agreement, however, isn't always fit if the post -verbal subject is a pronoun. In this case, the verb agrees in number, person and gender with the respective subject. We may look at (9) to explain this point (2).

9a nām -at hiya
slept fem,sg she, NOM

'She slept.'

9b. nam -atā huma
slept fem,DL both, NOM

'Both slept.'

9c. nim - na hunna
slept PL, fem they, NOM

'They slept.'

In short, the verb must agree in number, person and gender with the pronouns when they follow the verb. It is significance to mention that even if the pronoun occurs before the predicate, the latter has the set of agreement features of the subject. This issue poses a problem to the pattern of agreement in Arabic syntax to the extent why only pronouns detain the agreement features in the verb or the predicate in the two orders (see footnote 2 for the example).

1.3 The Problem

Insofar as agreement rules are concerned, there is no problem in regard to the agreement involving number, person and gender in S-predicate order if the subject is [+human] singular, dual or plural. Unlike Hindi, Arabic does not need sets of rules, one involving agreement between the verb and the subject NP, another involving agreement between the verb and the object NP and a third when the agreement is neutralized and the verb is third person, masculine and singular irrespective of the number, gender and person of the subject. The points that need to be captured are when the subject is plural masculine whether it is [- human] or [- animate]. In these cases, the feminine gender but not the masculine is the prominent as in (3-5). The Traditional Grammarians treated such subjects as feminine in the Agr and finally are listed exception to the rules of agreement and left without justifications. There are also other problems in agreement features involving person and number when the word order is VS as in (8). There is no regular pattern of agreement as that found in S-

predicate. Another perplexing problem is that there is no neutralization of agreement when the subject is a pronoun whether they precede or follow; there is a lack of logically expected agreement. It is not clear whether to list pronouns as nouns or to create a new set of rules that suit their occurrences in the structure [3]. After all, the Traditional Grammarians did not explain the nature of Agr in such issues and where the agreement is held. They were busy discussing the morphological realizations of the features appeared at the end of the lexical items at the phonetic form and didn't deal with it as a separate categorical or functional unit in syntax especially in Subj. predicate order in which Agr has strong features. They didn't provide syntactic reasons why the verb is always 3rd person singular in VS order, too. These issues of Agr created puzzles to the traditional and modern grammarians.

We refer to the theory of Agr of Chomsky (1995:349) to solve the problems of Agr in the previous analysis by examining the nature of Ø- features available in Arabic syntax and by categorizing Agr into strong or weak. We propagate that the formal features of strong Agr are checked by the predicate DP, Adj. or V at Spell-out. We will confirm that Arabic does not permit the deletion of strong Agr in nominal structures since it has a unique status in the sense that Ø- features are assigned to Agr as well as the substantive lexical predicate and are drawn straightforward from the lexicon. This assumption may not be literally compatible with what Chomsky (1995: 377) has said " As matters stand here, it seems reasonable to conjecture that Agr does not exist and that Ø- features of a predicate P, though – Interpretable, are like the Interpretable Ø- features of a noun in that they are part of P in the numeration, added optionally as P is selected from the lexicon". We argue that Agr is as essential as T or D as they bear formal features as other substantial elements at the interface levels in Arabic syntax. Thus, we posit a hypothesis, through which Agr functions are manifested in both word orders to solve the puzzle of agreement rules encountered in Arabic structures in a proper manner.

2. A THEORETICAL PERSPECTIVE OF AGR: A MINIMALIST APPROACH

2.1 Some Standard Assumptions of VSO and SVO in relation to Agr in Generative Grammar.

Languages differ from each other with respect to constituent's word order and agreement. Some have the structure of SVO in which the agreement is held between the subject and the verb and English is a specimen, some have SOV where the agreement is determined by the overt occurrence of the postposition. In other words, the verb agrees with unmarked DP as in Hindi and others have VSO in which the agreement is held between the subject and the verb as in Hebrew. However, Arabic involves both VSO and SVO simultaneously. In the former, the verb is always 3rd person singular whereas in the latter, it agrees in number, person and gender with subject DP in most cases. Our main concern is to study Arabic word orders in relation to Agr; we mention some assumptions about word-order formation from the generative grammar point of view in different languages. Fasi Fehri (1989) makes the assumptions for Arabic in (10):

10. (i) VSO order is derived by the verb movement to I.

(ii) SVO order is further derived by the subject raising to [Spec, IP].

On the contrary, Sproat (1985) has assumed that to get a VSO at PF in Welsh, there is the assumption (11):

11. V is in a projection higher than I; S is in [Spec, IP].

(10i) is not fit because if the verb is stuck in this position at PF, the subject DP remains in the [Spec, VP] which is a caseless position as per the VP-internal hypothesis.. However, in (11), a verb moves to a higher than the projection I and in this case the subject DP has the chance check the nominative case as it is close to TNS. (10ii) is fit because ;on one hand, the verb checks T and Agr and stations in I and ;on the other hand, the subject DP checks the proper case. As far as Agr rules in Arabic are concerned, we opt for Chomsky's theory of checking (1995) Minimalist Program.

2.2 The status of Agr in Minimalist Program

Chomsky (1995:349-355) has argued that functional categories, namely, T, C ,D and Agr play a central role in a language as they presume role in feature checking due to attract or move. The first three have interpretable features as they provide instruction at interface levels; however, Agr does not. It consists of interpretable formal features only. It is presented in syntax merely for theory internal reasons. Agr lacks Ø-features and independent case – assigning features, which is of course, provided by the V or T that adjoins to it. Ø- features of a predicate (V,Adj) are added to it for numeration as it is selected from the lexicon. If Agr is strong, its position is phonetically indicated by the overt categories raise to it, namely, V and T by adjunction and DP by substitution in [Spec, Agr]. However, if Agr is weak, then PF considerations give no reason for it to be present at all and LF consideration are not relevant. In short, the function of Agr is merely to provide a structural configuration

which features can be checked. These features are Case, Ø- features and categorical features [V-] and [T-] by adjunction and [D-] by substitution. The case assigning feature is intrinsic to the head [V,T] that raise to Agr for checking of DP in [Spec, Agr]. If Agr has Ø- features, they are interpretable as that of a noun or P as they are drawn from the lexicon and force raising of P. As for English, Agr is weak; therefore, it is eliminated from the lexicon; however as for Arabic, it is both weak and strong. The former will be decided to be narrowed and finally eliminated but the latter will not. We analyze both of them in the following section.

2.3.The Hypothesis

To account for the functions of Agr in Arabic, we posit the following hypothesis:

12i. In S - predicate structure, Agr is checked by adj or DP and α raises to [Spec, Agr] where α is a DP

ii In SV structure, Agr is checked by V and T merger but α remains in situ in [Spec, TP]] where α is a DP.

iii In VS structure, Agr is eliminated but α raises to [T, TP] where α is V.

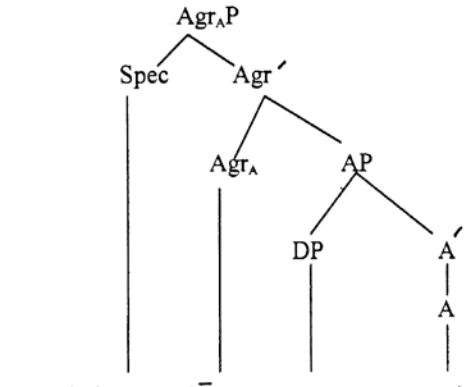
2.4 Strong Agr in S- Predicate

We refer to the hypothesis (12i) to derive the Subj.-predicate in which the latter is either an adjective or a DP. We argue that Agr is strong in this kind of structure and is derived straightforward from the lexicon as that of strong features of P or a DP. This is due to the fact that the predicate carries the same features of the subject and provides instructions at the interface levels. (13) illustrates the functions of Agr when the predicate is an adjective.

13a.	al	- jaw	-u	ḥārr	- un
	DET	weather	NOM	hot	NOM

'The weather is hot'

13b



the weather hot

In (13b), the DP 'al-jawu' *the weather* is merged in the position of t_1 in the AP as [Subj., Adj.] i.e,. (Subject of 'ḥarrun' *hot*), then raising to [Spec, Agr] for DP adjective agreement; however, not to [Spec, IP] for DP- verb agreement. The question that arises here: Do we need a strong functional category (Agr) to head the IP in the absence of V? Assuming that [Subj.,Adj.] is analogous to specifier or complement of V where theta roles are checked, agreement is checked in this position after merger. We argue that Ø- features of the adjective 'ḥarrun' are [+ interpretable] and are checked by the overt raising of its subject DP to [Spec, Agr] and of the adjective to Agr. As the process of checking is straightforward, we eliminate Agrs from the structure. In short, T is weak in this type of sentences; however, AgrP is the only substitute.

If we compare (13b) with the English counterpart (14), we see the function of Agr in AP clauses is entirely different.

14. [John is [t_1 Agr [t_2 intelligent]]].
IP AgrP AP

The DP *John* is merged in the position of t_2 in AP as [Subj., Adj.], raising to [Spec, Agr] for DP- adjective agreement, then on to the matrix [Spec, I] for DP- verb agreement. Chomsky (1995:353-354) argued that English [- interpretable] Ø- feature of the adjective 'intelligent' are checked by overt raising of its subject 'John' to [Spec, Agr] and of the adj. to Agr. He argued that as Agr is weak in English, the second raising is problematic. This problem can be avoided by eliminating Agr. In this case Adj is assigned the feature [nominal-] as it is drawn from the lexicon and the DP raises to the [Spec, I] required by the strong feature, entering the checking domain of Adj. thus, the structure of predicate adjective construction is not (14) but (15):

15. John is [t_1 [t_2 intelligent]].
AP A'

In short, for English Agr does not exist since agreement features of a predicate P though [- interpretable] are like the [+ interpretable] ones of nouns in that they are part of P in the numeration added optionally as P is selected from the lexicon (See Chomsky 1995: 377)

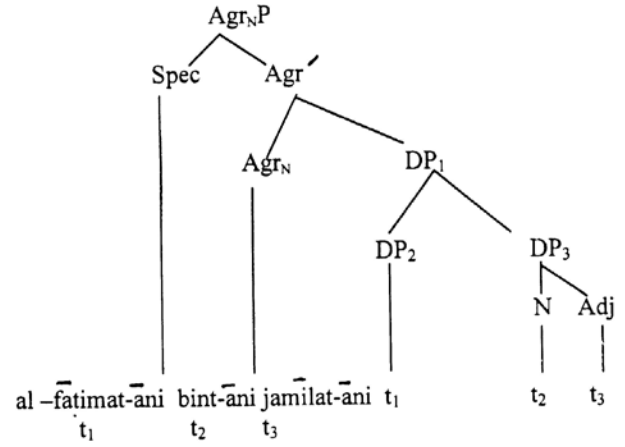
Recall (13b) and compare it to (15), we realize that in the former Agr is compulsory as it strong and the Adj is assigned the feature [nominal +] as it is drawn from the lexicon in nominal sentences in Arabic. We are at the right track because if the Adj does not have the interpretable feature, the resulting sentence will be incorrect as in [* 'al- jwani' *(dl,masc.)* 'ḥarrun' *(sg,masc.)* ' The both weathers are hot]. In other word the Adj is drawn from the lexicon carrying the same Ø- features of its subject, thus it must be 'ḥarrāni' *two hot* (dl, masc.). However, in (15) whether the subject DP is singular, dual or plural the Adj remains 'intelligent' as 3rd person and singular and genderless. We argue that Agrs, in (13b) is not needed because V is eliminated and its overt occurrence causes the ungrammaticality of the sentence as in [* 'al- jawu yakunu harrun' *the weather is hot*].

In short, if we deal with Agrs in Subj.- predicate constructions as that of English and eliminate it, T must be the substitute and the copula must be overt. In such case, the Adj ' harrn' has to be always third person singular regardless of its gender as that of *intelligent*, which, in fact, not the case in Arabic. In (13b), the DP checks merely once Agr features with Adj in AP shell and other similar agreement features attached to it which are visible at the output are drawn from the lexicon.

The hypothesis (12i) is also fit to explicate the strong Agr if the predicate is a DP. In this case, AgrP is needed but not the weak T. The specimen (16) illustrates the point

16a al- fātimat -āni bint -āni jamīlat -āni
DET Fatima DL girl DL beautiful DL
' Both Fatima are beautiful girls'

16b



det Fatima dl girl dl beautiful dl

It is obvious that in (16b) the DP_2' al- fātimatāni' *two Fatima* is merged in the position t_1 as the [Subj, DP_3] ' bintani jamilatani' *two beautiful girls.* DP_2 raises to [Spec, AgrP] for $DP_2 - DP_3$ agreement. However, the dual marker āni attached to DP_2 survives at all interfaces levels to confirm agreement at LF. Such feature is not liable for checking by the predicate DP_3. We may notice that Ø- features of the DP_3 are checked at [Agr_N, Agr] that heads the phrase. The dual marker 'āni' overtly marks the Adj 'jamīlatāni' because such features are drawn from the lexicon to modify DP_3.

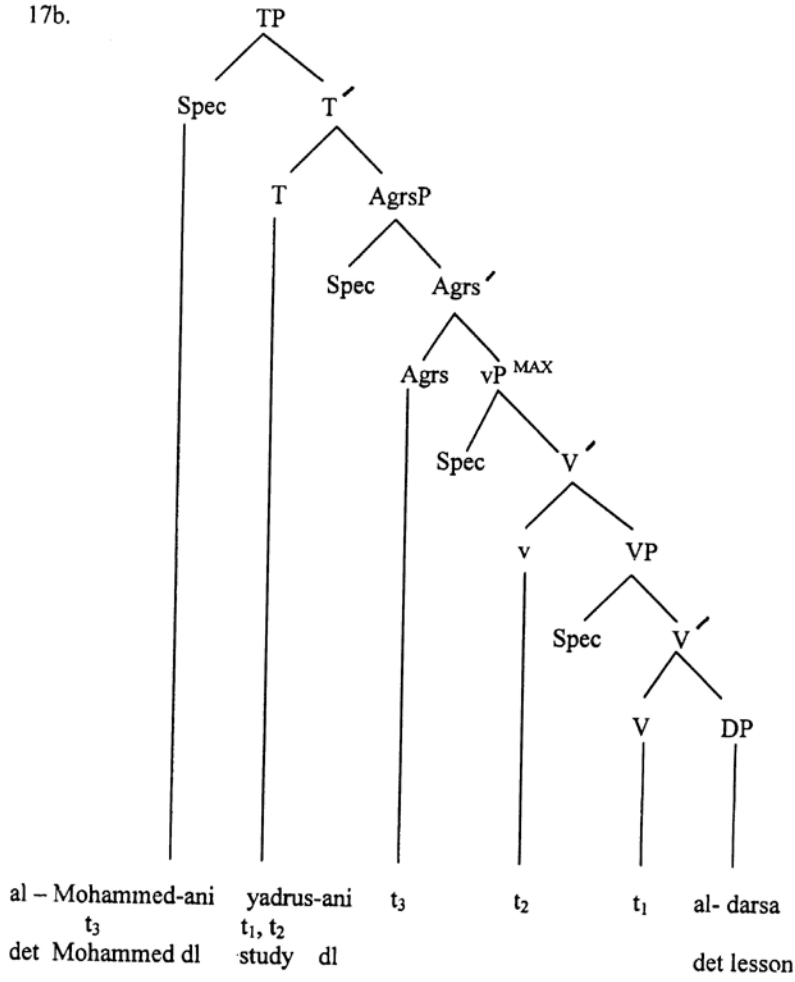
In short, Agr, in (16), is strong since the omission of any of its features from the predicate DP_3 will produce ungrammatical sentence.

To sum up, when the predicate is Adj or DP, Agr is strong and T is weak. The Agr features enforce the predicate to raise to it to be checked as they are interpretable features at LF.

The hypothesis (12ii) is fit, in this analysis, to account for the Agr features of the predicate V. We may look at (17) to explain the point.

17a. al- muḥamad -āni yadrus- Ø -āni al- dars -a
DET Mohammed DL study pres. DL DET lesson ACC
' Both Mohammed study the lesson'

17b.



In (17b), the verb 'yadrusu' *study* is located in t_1 in the VP shell; it checks the accusative case with the direct object 'al- darsa' *the lesson.* It raises to v for theta checking with the same argument. In a cyclic raising, it checks the formal dual marker ani in [Agrs, Agrs']. The question that arises here: Do we have to posit the DP in the [Spec, VP] shell? The answer is negative. As per the Principle and Parameter Theory (1993), the DP is to be posited in the respective position to avoid the multiple assigning of theta roles to the same argument. One is assigned in the VP shell and the other in the [Spec, IP]. Whereas as per the Minimalist Program (1995), [Spec, VP] is a non theta position because there is only one position to be checked [Spec,TP] to accommodate the economy condition that says " α enters the numeration only if it has an effect on output" (Chomsky 1995: 294). Recall the example (17b), the DP 'al-Mohammedani' remains in situ because; on one hand, the dual marker ani is a formal features that is not to be checked by V; on the other hand, the nominative case and the theta role are checked in the same assigned position i.e., [Spec,TP]. The Agr attracts

strong T for checking nominative case and T and V are merged for theta role as well as agreement checking. It is evident that the DP carries the strong Ø – formal features of V from the lexicon to emphasize the agreement at LF output.

In short, whenever the predicate is V,T and Agr are both strong. Agr cannot be eliminated because (17b) cannot have V as 'yadrus' which is 3rd person and singular. Likewise, T cannot be omitted since V cannot stand without tense.

If we recall the previous sentences (3-5), their problem is solved with the help of (12ii). The sentence (3) as a specimen is repeated here in (18):

18.	al-	qiṭaṭ	-u	ṣaᶜid	-at	al-	sullama	-a
	DET	cats	NOM,pl,masc	climb	fem, sg	DET	ladder	ACC

' The cats climbed the ladder'

As Agr is proved to be strong in this manner, the verb 'ṣaᶜidat' *climbed* retains the dominant feminine feature at. This is because Arabic treats [-human] plural nouns as singular feminine in Agr. The DP carries the formal features but V carries the Agr's. Wee may argue that even if some features of Agr are lost, still it retains one at least. Thus the problem is solved in this and other similar situations in (4) and (5).

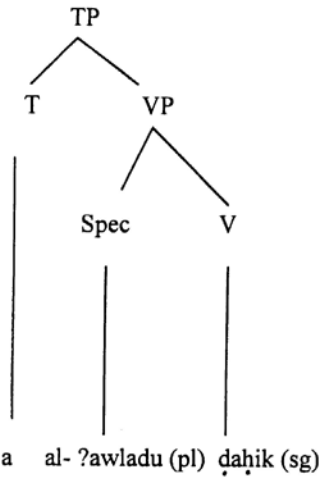
2.5 Weak Agr in V- Subject

The hypothesis (12iii) is worth referring to as it accounts for the verbal structures in Arabic in which Agr is weak and eliminated from the lexicon whereas T is strong. Agr does not at all attract V- raising, as there are no formal Ø –features at the interface level to be checked. The sentence (19) is a specimen to explicate the point.

19a.	ḍaḥik	-a	- Ø	al-	?awalād		-u
	laugh	past	3rd,sg,masc.	DET	boys		NOM

'The boys laughed'.

19b



The V 'ḍaḥik' *laugh* in (19b) raises to [T, TP] to check strong tense past. As Agr is weak, it is eliminated from the structure. T attracts V to check the nominative case in [Spec, T']. There are two questions to be answered in this tree diagram: (i) why Agr is eliminated? (ii) And why the subject DP 'al- ?awlādu' *the boys* remains in situ in [Spec, VP]? The answer to (i) is that Agr does not have [+interpretable] feature, which is needed, at the output of the interface. In other words, whether the subject is singular, dual or plural, the verb is always in the singular form. The Ø-features of the DP are basically formal and drawn from the lexicon and the verb 'dahik' is in default. However, the answer to (ii) is straightforward; it is due to the fact that the subject DP in this position is close to T, which attracts V to check the proper case in the position of [Spec,TP].

In short, as V has zero Agr features at Spell – Out as well as at LF it is eliminated exactly as that of English. The gender feature of V whether masculine or feminine that might appear in this order is interpreted as that of the Agr features of noun in that they are part of V in the numeration. They are added optionally as V is selected from the lexicon.

CONCLUSION

The hypothesis (12i) is fit to produce the nominal sentences (13&16) by placing the DP in the position of [Spec, AgrP]. It is decided that Agr in, such structures, is strong. It enforces the predicate Adj or DP to raise to the node Agr for checking the available interpretable features; however, other interpretable features are of the DP- subject are drawn from the lexicon to the predicate at LF. If we compare these two sentences with their English counterparts (14) and (15), we state that Agr does not exist in the latter since the predicate is always in a default form except that of 3rd person singular at the present tense. Thus, Chomsky (1995: 377) argued that the [- interpretable] features of P are like the [+ interpretable] ones of the DP are part of P in the numeration and added to it from the lexicon. As a result, P in (13) and (16) has always [+ interpretable] features which are forcibly added to it in the lexicon thus it is part of P in the numeration.

The hypothesis (12ii) is worth referring to as it accounts for distribution of Agr features to produce a grammatical nominal sentence by placing the DP in the position of [Spec, TP] as in (17b). Agr and T are both strong. The former attracts the latter for checking the nominative case as well as Ø - features. It also attracts V to raise to [T, T'] to check proper theta roles. Agr is proved to be strong here because the predicate V carries strong Ø-features though the same are attached to the DP. We argue that the repetition of overt marking in the DP indicates emphasis at LF output. As Agr is proved to be strong in S- predicate order, (12ii) is a helpful mechanism to solve the problematic sentence (18), which doesn't follow the regular pattern of agreement rules posited by the Arab Traditional Grammarians. It is because the predicate 'ṣaᶜida' *climbed* isn't permitted to carry the regular plural masculine marker u but it carries the singular feminine marker at, in stead. The hypothesis is fit in dealing with such structures in the sense that even if the regular pattern of Agr is lost, still Agr retains the available permitted marker especially the at. This application of Agr, of course, matches the general practice in Arabic as it deals with [- human and - animate plural nouns] just like plural feminine insofar gender and number are concerned.

However, the hypothesis (12iii) is suitable to produce the verbal order of elements by leaving the DP in situ in the position of [Spec, VP] as in (19b). It is decided that Agr is weak and eliminated from the structure. The predicate V doesn't perform or carry any kind of markers except the masculine and it remains in the form of 3rd person singular. However, T is undoubtedly strong; it attracts V raising for case checking but not for Agr.

To sum up, Agr has two primary faces in UG. One is strong and the other is weak. Whenever there are overt agreement markers appear at the predicate and other substantive lexical items, it cannot be eliminated from syntax. We said so because the deletion of any Agr feature from the elements produces ungrammatical sentences, particularly in Suj.- predicate order. However, if Agr is weak the predicate does not carry strong features similar to the ones attached to the DP. As there are no features to eliminated or checked it is cancelled from the structure in Arabic especially in verbal order.

Thus, Agr remains a part of syntax though some of its functions are narrowed in UG. We feel that it is as essential as T because it is the only substitute whenever there is no overt T. In other words, there are grammatical sentences in Arabic in the

absence of T but this cannot be in the absence of Agr, particularly, in nominal structures at all levels of syntax.

FOOTNOTES

- It is evident that in Subj.- predicate order whether the predicate is a DP or Adj, it must agree with the subject in all Ø-features as in (1) and (2) respectively.

1i.	zaid	-un	[DP	waladun		nasiṭun]
	Zaid	NOM,sg,masc		boy (sg)		active (sg)
			' Zaid is an active boy'			
ii.	al-	zaid	-āni	[DP	waladāni	nasiṭāni]
	DET	Zaid	NOM,dl		both Zaid (dl)	active (dl)
			' Both Zaid are active boys'			
iii.	al-	ziyūd	-u	[DP	?awalādun	nasiṭun]
	DET	Zaid	NOM,pl		boys (pl)	active (pl)
			' Zaid (pl) are active boys'			
2i.	walad	-un		[AP	ṭawīlun]	
	boy	NOM,sg,masc.			tall (sg),masc	
			'A boy is tall'			
2iii.	walad	-āni			[AP	ṭawīlāni]
	boy	NOM,dl,masc				tall (dl), masc
			'Both boys are tall'			
2ii.	?awalād	-un		[AP	ṭiwālun]	
	boy	NOM,pl,masc			tall (pl),masc	
			' Boys are tall'			

2. If the pronoun precedes the predicate, the latter carries the same features of the subject.

1i.	huwa	nāma	-o		
	he	slept	3rd,sg,masc.		
			'He slept'		
2ii.	Hum	-a		nām	-ā
	both	dl,masc		selpt	dl,masc.
			'Both slept'		
2iii	Hum	-o	nām	-u	
	both	pl,masc	selpt	pl,masc.	
			'They slept'		

TRANSLITERATION OF THE ARABIC WRITING SYSTEM

Translit-eration	Phonetic Value	Translit-eration	Phonetic Value
?	?	d	đ
b	b	t	ṭ
t	t	z	ẓ
t;th	θ	c	ʿ
j	d3	g;gh	ɣ
ḥ	ħ	f	f
x;kh	x	q	q
d	d	k	k
d;dh	ð	l	l
r	r	m	m
z	z	n	n
s	s	h	h
š;sh	ʃ	w	w
ṣ	sˁ	y	y
Short vowels		Short vowels	
a	a	ā	a:
u	u	ū	u:
i	i	ī	i:

ABBREVIATIONS

A	Adjective
AP	Adjective Phrase
Adj	Adjective
ACC	Accusative
Agr_AP	Agreement Phrase
Agr	Agreement
Agr_NP	Agreement Noun Phrase
AgrP	Agreement Phrase
C	Complementizer
D	Determiner
DET	Determiner
DL	Dual
DP	Determiner Phrase
Fem	Feminine
IP	Inflectional Phrase
Masc.	Masculine
NOM	Nominative
NP	Noun Phrase
P	Predicate
Pl	plural
Pres.	Present
S	Subject
Spec	Specifier
Sg	Singular
SVO	Subject, verb, object
S	Subject
Subj.	Subject
T	tense
TP	Tense Phrase
UG	Universal Grammar
V	Verb
VP	Verb Phrase

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