BRIEF HISTORY OF THE CONCEPT "CONSTRAINT" IN GENERATIVE PHONOLOGY

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"As originally conceived, the *RULE* of grammar was to be built from a Structural Description delimiting a class of inputs and a Structural Change specifying the operations that altered the input (e.g. Chomsky 1962). The central thrust of linguistic investigation would therefore be to explicate the system of predicates used to analyze inputs - the possible Structural Descriptions of rules - and to define the operations available for transforming inputs - the possible Structural Changes of rules. This conception has been jolted repeatedly by the discovery that the significant regularities were to be found not in input configurations, nor in the formal details of structure-deforming operations, but rather in the character of the *output* structures, which ought by rights to be nothing more than epiphenomenal. We can trace a path by which 'conditions' on well-formedness start out as peripheral annotations guiding the interpretation of rewrite rules, and, metamorphosing by stages into constraints on output structure, end up as the central object of linguistic study." (Prince & Smolensky, 1993: 1)

1. INTRODUCTION

Starting from the statement in the first page of Prince and Smolensky (1993[2004]), I tried to make explicit the path "by which 'conditions' on well-formedness start out as a peripheral annotations … and … end up as the central object of linguistic study". In order to accomplish this historiographical tour I traced back the most significant appearances of theoretical devices functionally similar to 'constraints', paying attention to prominent works produced in the generative phonology framework:

- Wells, R., (1949), "Automatic Alternations", in *Language*, 25, pp. 99-116.
- Halle, M., (1959), *The Sound Patterns of Russian*, The Hague, Mouton de Gruyter.
- Stanley, R., (1967), "Redundancy Rules in Phonology", in *Language*, 43, pp. 393-436.
- Chomsky and Halle, (1968), *The sound pattern of English*, New York, Harper and Row.
- Kisseberth, C., (1970), "On the Functional Unity of Phonological Rules", in *Linguistic Inquiry*, 1, pp. 291-306.
- Shibatani, M., (1973), "The Role of Surface Phonetic Constraints in Generative Phonology", in *Language*, 49, pp. 87-106.
- Goldsmith, J., (1976 [1979]), *Autosegmental Phonology*, New York, Garland Publishing.
- Singh, R., (1987), "Well-formedness Conditions and Phonological Theory", in Dressler et al. (ed.), *Phonologica 1984*, Cambridge, Cambridge University Press.
- Paradis, C., (1988), "On Constraints and Repair Strategies", *The Linguistic Review*, 6, pp. 71-97.
- Scobbie, Coleman and Bird, (1996), "Key Aspects of Declarative Phonology", in Durand and Laks (eds.), *Current Trends in Phonology: Models and Methods*, 2, European Studies Research Institute (ESRI), Salford, Manchester, UK, pp. 685-709.
- Smolensky, P., (1986), "Information processing in dynamical systems: Foundations of harmony theory", in Rumelhart, McClelland and PDP Research Group (eds.), *Parallel Distributed Processing: Explorations in the Microstructure of Cognition*, Cambridge, MA, Bradford Books/MIT Press, pp. 194-281.
- Prince and Smolensky, (1993 [2004]), Optimality Theory: Constraint Interaction in Generative Grammar, Blackwell Publishers.

Particular attention has been devoted to contexts and motivations that fostered the increasingly use of the 'constraint' and the improvement of its formalization, in order to better comprehend where this device come from and how it dethroned the 'rule' becoming the keystone of contemporary generative phonology architecture.

2. CONSTRAINT FORMALIZATIONS

2.1. Halle (1959): Distributional constraints, Morheme Structure Rules.

They account for the distribution of features in Russian segments (Segment Structure Rules, SSR) and morphemes (Morpheme Structure Rules, MSR), so as to let morphemes maximally underspecified. Their formalization is not so straightforward: sometimes they are formalized as sequences of symbols that define the major phonological classes of segments (ex.: VJC, etc.), sometime they are called 'rules':

> "The constraints […] have to be taken into consideration in representing the individual morphemes in the dictionary since they make it possible to leave unspecified various features in the representation of certain morphemes […] It is not possible to give a complete procedure for discovering the most economical representation in every case. *The best that can be done is to formulate the sequential constraints as rules specifying certain contexts*. The representation of every morpheme then has to be chosen in such a way as to take maximum advantage of these rules, while at the same time leading the correct phonetic consequences." (Halle, 1959: 57)

Two of the MSRs presented by Halle (1959) are the following:

1) "Rule MS 1a. If the segment following the & marker [morpheme boundary] is a glide, the next segment is vocalic and nonconsonantal; i.e. a vowel."

2) "Rule MS 5d. If the last segment is a consonant and the penultimate segment is a glide, the glide is preceded by a segment which is vocalic and nonconsonantal."

According to 2) in a sequence like VJC&, we can underspecify the first segment relatively to the feature [voc] e [cons]: 2) will block the derivation [ ]JC& > *CJC&, favouring instead [ ]JC& > VJC&. However, if we consider a morpheme like {'ajv}, 'quince', 2) alone can lead us to propose a wrong representation: given the fact that the first segment is underspecified, we don't know if it is a vowel or a glide. This, in turn, imply that when we recover this (underspecified) morpheme from the lexicon we don't know if we have to apply 1) or 2). Now, if we applied 1) the second segment would have to be a vowel, instead of the expected glide. In order to solve problems like this Halle (1959) state that MSRs cannot change the value of the features (here, in the second segment, [-voc] > [+voc]), and this allow him to maintain the ordering of MSR, which in turn allow MSRs to be more economic and general (even if in a linguo-specific domain).

Now, given the fact that MSRs can be considered as functions that map sequences that conform to a structural description to the sequences described by distributional constraints, blocking at the same time wrong mappings, the similarity between MSRs and 'constraints' (/well-formedness conditions) is straightforward. This is evident in 3), a more 'rule-like' form of 2):

3) $0 \rightarrow \begin{bmatrix} + & \text{voc} \\ - & \text{cons} \end{bmatrix} / \_ \begin{bmatrix} - & \text{voc} \\ - & \text{cons} \end{bmatrix} \begin{bmatrix} - & \text{voc} \\ + & \text{cons} \end{bmatrix} \#$

We can see here how this MSR maps the matrix that constitutes its structural description ([ ]JC&) to the underspecified morpheme (VJC&), and how this process can be consider functionally similar to both a 'constraint' on the surface structure and an algorithm that complete the specification of the matrices of Russian.

2.2. Stanley (1967): Morpheme Structure Conditions.

Stanley (1967) modifies the grammar architecture of Halle (1959) and replaces MSRs with Morpheme Structure Constraints (MSC), whose only function is to account for the phonological structure of morphemes. This enables the grammar to keep statements about morpheme phonological regularities distinct from processes that handle redundancy. His model is made of two distinct component:

a) an ordered set of MSC, M, which define a set, M(U), of fully specified morpheme matrices, S_m (with *n* row, where *n* is the number of segments, and *i* columns, where $1<i<\lambda$ and λ is the highest number of segments in a morpheme of a given language)

b) a selective process whereby, given a morpheme *m*, the underspecified lexicon matrix D_m select a fully specified matrix S_m from M(U)

Summarizing:

> "MS conditions give statements of constraints, while the process of selection uses these statement to predict redundant feature values. Thus, statement of constraints and prediction of redundancies, though intimately related, are given as separate processes." (Stanley, 1967: 425)

Stanley (1967) presents three kinds of MSC:

c) IF-THEN CONDITIONS:

> "An if-then condition C is a pair of matrices I(C) and T(C), the 'if' and the 'then' part of the condition respectively, where I(C) and T(C) are each incompletely specified matrices which have *n* rows (one for each distinctive feature) and entries '+', '-', or no entry (blank). Further, I(C) and T(C) have the same number of columns and are disjoint. The if-then condition C has the following interpretation: for all matrices M in U such that I(C) is a sub-matrix of M, C ACCEPTS M if T(C) is also a sub-matrix of M, and C REJECTS M if T(C) is distinct from M; if I(C) is distinct from M, then C accepts M regardless of what T(C) is." (Stanley, 1967: 426)

In the following example I(C) and T(C) are sub-matrices of the same M (the fully specified corresponding matrix in U), so this IT(C) accepts the morpheme and complete the specification of the features:

4)

$$I(C) + [+cons] \quad \begin{bmatrix} +cons \\ -voc \end{bmatrix}$$

$$T(C) \begin{bmatrix} -voc \\ -grave \\ -comp \\ +cont \end{bmatrix} \quad [-cont]$$

d) POSITIVE CONDITIONS:

This kind of MSC consist of an underspecified matrix, P(C): all the matrices in U whereof P(C) is a sub-matrix are accepted, the others refused.

5)

$$P(C)+\begin{bmatrix}+ & cons\\ - & voc\end{bmatrix}\left(\begin{bmatrix}+ & cons\\ + & voc\end{bmatrix}\right)\begin{bmatrix}- & cons\\ + & voc\end{bmatrix}([+cons])$$

In 5) P(C) accepts all the matrices that have the structure $C(L)V\binom{C}{L}$.

e) NEGATIVE CONDITIONS:

As P(C), N(C) too is made of a single matrix. The difference is that N(C) refuses all the matrices of U whereof N(C) is a sub-matrix. In the following example (where "~" corresponds to "*" of OT) N(C) can account for the fact that Russian accepts [ts], [ʃ] and [ʒ], but excludes [dʒ].

6)

$$N(C)\sim\begin{bmatrix}-vocalic\\ +compact\\ +grave\\ +continuous\\ +voice\end{bmatrix}$$

Another example is the distribution of the features [voice] and [asp] in IE obstruent-vowel-obstruent sequences.

7)

*pedh	ped	pet
bedh	*bed	bet
bhedh	bhed	*bhet

Here the specification of the feature [voice] in the first segment cannot be the opposite of the one of the feature [asp] in the last segment, and the specification of [voice] in the last cannot to be the opposite of the one of [asp] in the first segment (cfr. Bartholomae's Law). This generalization is correctly stated by the following N(C):

8)

$$\text{N(C)} \sim + \begin{bmatrix}\alpha & \text{voice}\\ \beta & \text{spread glottis}\end{bmatrix}\begin{bmatrix} \quad \end{bmatrix}\begin{bmatrix}-\beta & \text{voice}\\ -\alpha & \text{spread glottis}\end{bmatrix} +$$

> "It is of course necessary that many examples of negative conditions be given if their introduction into the theory is to be motivated. An important line of research would be to discover to what extent negative conditions describe situations which occur in natural languages." (Stanley, 1967: 433)

As we know, his wishes will be honoured…

2.3. Chomsky & Halle (1968): Morpheme Structure Conditions, Markedness Conventions.

In the first part of SPE Chomsky & Halle use the same devices presented in Halle (1959) (MSR), which here are called Morpheme Structure Condition. Like the "old" MSR, the "new" MSC are devices that can be considered at the same time redundancy rules and constraints on the well-formedness of morphemes:

> "…the redundancy rules be interpreted as conditions on the lexicon, rather than as rules to be applied in sequence in the manner of phonological rules. They can be thought of as filters that accept or reject certain proposed matrices but that do not modify the feature composition of a matrix as a phonological rule does." (Chomsky & Halle, 1968: 388).

However, in the 9th chapter they propose, in order to solve problems deriving from the excessively formal approach to phonology, a new theory: they introduce an ordered set of (universal interpretive) Markedness Conventions, which:

> "state not only constraints on feature combinations within segments, but also constraints on segment sequences." (Chomsky & Halle, 1968: 416)

They can be considered as a couple of devices, formally similar to phonological rules, which describe two disjunctive feature configurations (*u*F and ¬*u*F) in a segment or in a morpheme:

9) [*u*F] → [αF]/X_Y"

In 10) for example we have one of the conventions proposed by Chomsky & Halle (1968), according to which the unmarked specification of the feature [cont] is [+cont] before a consonant, and [-cont] in all the other contexts:

10)

$$(XXIV) \quad [u\ cont] \quad \rightarrow \quad \begin{Bmatrix} [+cont] / + \_ [+cons] \\ [-cont] \end{Bmatrix}$$

An interesting property of Markedness Conventions is that they contribute to the simplification of the rule. In slavic languages, for example, we have a process known as first velar, whereby /k/, /x/ and /g/ became [ts], [ʃ] and [ʒ] when followed by [-back] vowels or glides (Chomsky & Halle, 1968: 422). This has been traditionally accounted for by the following rule:

11)

$$[-front] \quad \rightarrow \quad \begin{bmatrix} -back \\ +cor \\ +del\ rel \\ +strid \end{bmatrix} \quad / \_ \begin{bmatrix} -cons \\ -back \end{bmatrix}$$

Now, if we consider the following Markedness Conventions:

12)

$$(XXIIIb) \quad [u\ cor] \quad \rightarrow \quad [+cor] \quad / \quad \begin{bmatrix} -back \\ -front \end{bmatrix}$$

13)

$$(XXVIa) \quad [u\ del.rel.] \quad \rightarrow \quad [+\ del.rel.] \quad / \quad \begin{bmatrix} \overline{-\ front} \\ +\ cor \end{bmatrix}$$

14)

$$(XXVIIc) \quad [u\ strid] \quad \rightarrow \quad [+\ strid] \quad / \quad \begin{bmatrix} \overline{+\ del.rel.} \\ +\ cor \end{bmatrix}$$

…11) can be transformed in 15):

15)

$$[-\ front] \quad \rightarrow \quad [-back] \quad /\ \_ \begin{bmatrix} -\ cons \\ -\ back \end{bmatrix}$$

Given that Economy is considered a pivotal principle in the process of evaluation of possible grammars, the effect of reducing rules' structure is a good result.

As we suggested above, Markedness Conventions can be considered as formalizations of (universal) preferences relative to the co-occurrence of features, hence is fair to recognize a certain parallelism with more recent constraints: like OT violable markedness constraint, ranked (universal) Markedness Conventions can be seen as a couple of (interpretive markedness) constraints, which are obeyed according to the limits imposed by the specification of contrastive features, hence, by a kind of "faithfulness pressure".

2.4. Kisseberth (1970): Derivational Constraints.

> "The standard theory says there is no other way in which rules can be the 'same' except structurally. This position can, I believe, be demonstrated to be incorrect. The unity of a set of rules may not rest upon the similarity of their structural descriptions, but rather upon the similarity of their *function*. Or to put the point in a slightly different way, rules may be alike in having a common *effect* rather than in operating upon the same class of segments, or performing the same structural change" (Kisseberth, 1970: 293)

Kisseberth (1970) introduce the concept of 'conspiracy' to describe the situation in which a set of formally unrelated rules seemingly plot to obtain the same effect, the same output representations. These target representations are here defined in terms of derivational constraints: if the application of a rule entail the violation of a constraint, then it is blocked, while if its application can remove a violation, then it is triggered.

As an example, Kisseberth (1970) consider these sets of data from Yawelmani:

16)

	'to lift up'	desiderative	future
	hala:l	+ *hatin*	+ *i:n*
zero stem formation	*hall*	+ *hatin*	+ *i:n*
consonant reduction (rule 18d))	*hall*	+ *atin*	+ *i:n*
vowel deletion (rule 18f))	*hall*	+ *atn*	+ *i:n*
other rules	*hall*	+ *atn*	+ *en*

17)	'armpit'	passive consequent adjunctive	protective vowel	locative
vowel epenthesis (rule 18a))	*giti:n*	+ *hnil*	+ *a*	+ *w*
consonant reduction (rule 18e))	*giti:n*	+ *nil*	+ *a*	+ *w*
other rules	*giten*	+ *ne:l*	+ *a*	+ *w*

All these facts can be accounted for by the following rules:

18) a. 0 → V / C_C# d. C→ 0 /CC+_

b. 0 → V / C_CC e. C→ 0 / C+_C

c. $0 \rightarrow V$ / C_C $\left\{ \begin{matrix} \# \\ C \end{matrix} \right\}$ f. $\left[\begin{matrix} V \\ -\text{long} \end{matrix} \right] \rightarrow 0$ / VC_CV

Now, all these rules, except for 18a) and 18b), which can be collapsed together in 18c), are not formally similar, but can be seen as a set of rules which share the same aim: to block ill-formed output configurations resulting from morphological processes. These ill-formed output configurations are stated in terms of derivational constraints:

19) *CCC *#CC *CC#

In other words, Kisseberth (1970) inserts in the phonological grammar, beside a set of standard rules, a set of rules which are dependent on constraints that are defined, for the first time, on the output structures. As he observes, however:

> "The above comments must be taken as simply the first tentative step in the construction of a theory of phonology employing the notion of derivational constraints. Its seems to me to offer a fruitful framework from which to investigate one significant aspect of a general phenomenon of rule relatedness." (Kisseberth, 1970: 305).

2.5. Shibatani (1973): Surface Phonetic Constraints.

In the framework of Natural Generative Phonology, beside the wish to reduce the abstraction level (Kyparsky, 1968) and to enrich the representations (syllable), the functional motivation of rule application and its formalization is still a central issue, as shown in the following quotatation:

> "A P-rule R is positively motivated with respect to a phonotactic constraint C just in case the input to R contains a matrix or matrices violating C AND the set of violations of C found in the output of R is null or is a proper subset of the set of such violations in the input to R." (Sommerstein, 1974: 74).

In this context Shibatani (1973) applies the same formal language used by Stanley (1967) to define morphemic constraints in order to describe generalizations occurring in the surface level. He therefore introduces Surface Phonetic Constraints (SPC), which can be divided in three typologies:

f) POSITIVE SPCs:

Their goal is to define well-formed syllabic structures. As an example consider the SPC in 20):

20) $\#(CV)_1\#$

The presence of this SPC in the phonological grammar of a given language implies that a word can be considered well-formed if it's composed of one or more CV sequences. Another example is 21), a SPC Shibatani (1973) proposes for Japanese, where le only possible word-final Coda is a nasal:

21)

$$P(C)\#((C)\ (G)\ V\ (C)\#$$

$$|$$

$$n_{o}\ /\ \_\ \#$$

The need of this SPC is particularly evident in cases of loan word adaptation, where, as shown in 22a), loan word is accepted if it has a word-final nasal Coda, while, if it has a structure violating 21), it is modify via epenthesis (22b)):

22)	a.	Eng.	*pen*	>	Jap.	*pen̥*
	b.		*script*	>		*sukuriputo*

g) IMPLICATIONAL SPCs:

Shibatani (1973: 89) introduces this kind of SPC to account for, for example, the distribution of [nasal] feature in a hypothetical language which admits the following forms:

23) ma, *mã, bã, ba

The following are the SPCs which account for 23):

24)	a.	IF:	[↓]	[+ nas]
		THEN:	[- nas]	
	b.	IF:	[+ nas]	[↓]
		THEN:		[- nas]

h) NEGATIVE SPCs:

Shibatani (1973) admits that the effect of some implicational SPC can be more economically replicated by a negative SPC. 24) for example can be substituted by the following NPC:

25) N(C) ~[+ nas] [+ nas]

Summarizing, Shibatani (1973) contributes to the "emergence" of phonotactic constraints from morpheme to surface structures and assigns them a relevant status:

> "It is the SPC's of his native language which intrude into the pronunciation of a foreign language when an adult learner speaks. The SPC's are acquired in an early stage of mother-tongue acquisition, and they are deeply rooted in the competence of a native speaker." (Shibatani, 1973: 99)

2.6. Goldsmith (1976): Well-formedness Conditions.

By the end of the seventies 'representation' becomes the central issue in phonological theory, the central tenet of this approach being the Well-formedness Condition (WFC):

> "It is […] reasonable, in any case useful, to establish a strong bond between representations and well-formedness: only representations can be well- or ill-formed, and something can only be a representation if it can be ill-formed." (Scheer, 2009: 16)

So 'representation' becomes richer, but it has to respect a set of constraints that define his structure, as the one in 26), exemplified in 27):

26) a. Every tone should be associated to at least one tone

b. Every vowel should be associated to at least one tone

c. Association lines are not allowed to cross

27) archipelago archipelago archipelago

H L H L H L

These kinds of constraints, in other words, define general preferences for the linking between tones and vowels, which can trigger rules (spreading) that ensure that these requirement are obeyed. The result is a well-formed surface representation, and the triggered rules can be considered 'repair strategies' mechanisms.

WFCs, as already told, gain a central status in phonological grammars, because:

> "… to write separate rules where each specifies the particular way in which a phonotactic can be violated – and to call that, then, the 'structural description' of the rule, as if it were that particular sequence that caused the rule to apply, rather than the representation's failure to satisfy the phonotactic – is to miss a string of important generalizations." (Goldsmith, 1990: 322)

To summarize:

> "What is clear is that any serious theory of phonology must rely heavily on well-formedness constraints; where by 'serious' we mean 'committed to Universal Grammar'. What remains in dispute, or in subformal obscurity, is the character of the interaction among the posited well-formedness constraints, as well as the relation between such constraints and whatever derivational rules they are meant to influence. Given the pervasiveness of this unclarity, and the extent to which it impedes understanding even the most basic functioning of the grammar, it is not excessively dramatic to speak of the issues surrounding the role of well-formedness constraints as involving a kind of conceptual crisis at the center of phonological thought." (Prince & Smolensky 1993: 1)

2.7. Singh (1987): Generative Phonotactics, Constraints.

As noticed in the preceding quotation, the dependency relation between phonotactic conditions and rules, which are becoming simpler and simpler, constitutes a central topic in phonological bibliography (Kisseberth, 1970; Sommerstein, 1974; Hooper, 1976; Goldsmith, 1976, 1993). Now, according to authors like Singh (1987), 'rule' has to be substituted by a set of universal repair strategies which serve to remove violations of a set of linguo-specific WFCs.

The following is the analysis Singh (1987) proposes for English plural, whereby we have two WFCs (28)) and two repair rules (29)):

28)

29) a. [+ obst] > [-voice] b. Ø > ɪ
[+ voice]

ex.: *cats* *[kætz] > [kæts] *classes* *[klæsz] > [klæsɪz]

Singh (1987), furthermore, proposes the following Repair Principle:

> "If a violation cannot be repaired by replacing the offending, degenerate, boundary segment with a member of the same class [rule 29a)] then, and only then, the degenerate segment should be set up as a separate syllable [rule 29b)]" (Singh, 1987: 278)

The decision among these two different solution is carried out by the Structure Preservation Principle, which prefers repair that minimally modifies input structure.

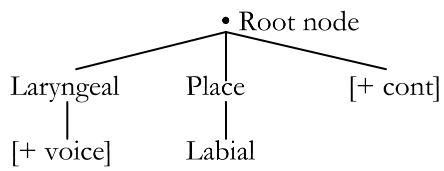
2.8. Paradis (1988): Constraints and Repair Strategies

Paradis (1988) proposes a model similar to the one presented by Singh (1987), with a set of WFCs and a set of universal repair strategies. The main difference lies in the fact that Paradis' WFC are both linguo-specific and universal: all WFC are stored in UG and are parametrically activated. Furthermore, in her model constraints can conflict: this can happen because of either an underlying ill-formedness or different repairs. As in Singh (1987), this kind of conflict is solved by a Structure Preservation Principle, which preserve as much input structure as is allowed by constraints. In addition, Paradis (1988) links the Structure Preservation Principle to a universal Phonological Level Hierarchy:

i) metrical level > syllable > skeleton > root node > class node > feature

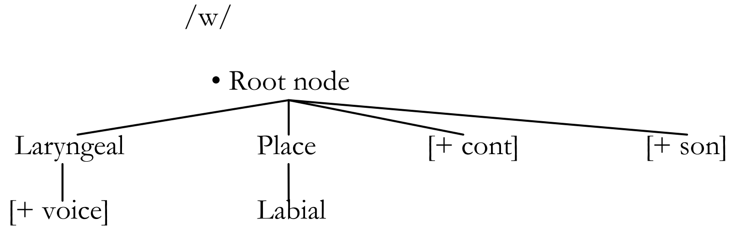
If, for example, a given structure violates two constraints, the most important to obey to is the one that hold in the higher domain. As an example Paradis (1988) considers a process of loan word adaptation from French to Fula, whereby French /v/ emerges in Fula as a [w]. /v/ is assigned the following representation (cfr. Paradis, 1995):

30) /v/



In Fula, however, there is a constraint that ban [+voice] and [+cont]to occour in the same segment, except if [+son] is present as well. To obey this constraint we could delete this segment, but this process would be in contrast with the wish expressed by the Structure Preservation Principle, so Fula prefers to add [+son] feature, i.e. to apply a repair strategy at the lowest level of the hierarchy in i):

31)



In her model, then, Paradis (1988) repairs are dependent and proportional to violations: this means that for every violation there is a repair strategy that can eliminate it and, hence, that no surface violation is admitted (they are admitted only in the intermediate stages of derivation).

2.9. Scobbie *et al.* (1992): (hard) Constraints.

Another constraint-based approach developed in the eighties is Declarative Phonology (DP). Here too transformational rules are banned, as is the general concept of ordered derivation, but in a more radical way: the softest version of the standard rule, i.e. the repair strategies we've seen, are banned as well. To account for phonological generalization then, DP resorts to hard (inviolable) constraints, which cannot be violated in any level (given that DP doesn't admit derivation processes, there cannot be any level except for the lexical and superficial one, and it makes no sense to admit an intermediate violation, as in Paradis (1988)).

Formally, constraints in DP are descriptions:

> "*every* element of the phonology is a description of the intended phonological object. Each statement is a *partial* description, since it only refers to a tiny characteristic of the object concerned." (Scobbie, Coleman e Bird, 1996: 687).

The following is an example of DP at work in a sentence as *Sofia eats*, in which an epenthetic [ɹ] constitutes the onset of the last syllable:

32) a. Lexical entries: <səufɪə(ɹ)> 'Sofia' <i:ts> 'eats'

b. ɹ → *dom* (onset, ɹ)

c. ¬ <V[-high].V>

Sofia eats > /səufɪəɹi:ts/

In 32) syntax gives the phonology a couple of surface constraints, the first of 32a) being a partial description in which [ɹ] alternates with 0, and two more constraints: 32b) states that if it there is a [ɹ], then it has to be an onset, while 32c) bans every hiatus in which the first element is [-high]: in other words, 32c) bans a sequence like */səufɪəi:ts/, by letting [ɹ], which is already present in the relevant lexical entry, to emerge in onset position, as required by the constraint in 32b).

As can be noticed, the price constraints have to pay in order to be obeyed is the loss of universal character: they are indeed very complex and linguo-specific.

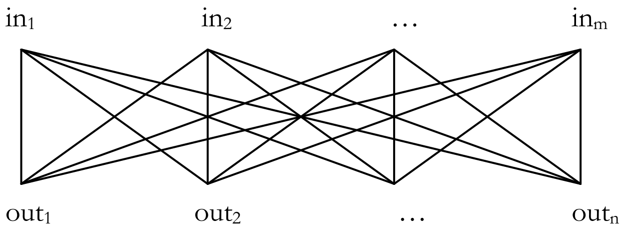
2.10. Smolensky (1986): Connectionism and Harmony Theory.

Another important element to be considered to better understand OT constraint is the one introduced in linguistics by Smolensky (1986). In his Harmonic Theory he tries to develop a synthesis between connectionist and symbolic approach to computation:

> "Harmonic Theory [is] a mathematical framework for studying a class of dynamical systems that performs cognitive tasks according to the account of subsymbolic paradigm […] The ultimate goal of the enterprise is to develop a body of mathematical results for the theory of information processing that complements the results of the classical theory of (symbolic) computation." (Smolensky, 1986: 195)

As we see from the quotation, the objects of his study are dynamical systems, i.e. complexes of numerical variables that evolve parallel, directed by differential equations. These objects are known as 'neural networks':

33)



A neural network is a device that maps an input representation to an output representation. These representations are defined in terms of configurations of (constant) activity level, which are connected one to another by a set of connections. Every connection has a numerical value that define its weight: if in_i and out_j are respectively the input and output configurations, the weight will be w_{ij}. Once this architecture has been defined, it is given a set of input-output pairs so as to find the weight configuration that performs the right mapping. After this training stage the network is given new inputs to test the correctness of weight configurations obtained in the previous stage: if weight are the right ones, i.e. if the network has acquired the grammar, then the expected output representations emerge.

It's now possible to state a similarity between weights and constraints: the correct input-output mapping is a consequence of the best weight configuration offered by the network. Furthermore, a negative weight can be interpreted as a formalization of the fact that a grammar prefers not to map a given input into a given output, while a positive weight state a well-accepted mapping. In addition, absolute numerical value translates how much a grammar "likes" given mappings: the more is high, the more the constraint is strong (cfr. Prince e Smolensky, 1997: 1607):

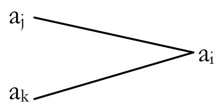
34)

a_i	w_{ij}	a_j	harmony value
a_i	← -2 →	a_j	
+1	←→	+1	-2
-1	←→	+1	+2

Given that a network is made of a lot of associations like this, the harmony value of the network is the sum of all single harmony values, which are the products of input activity level, connection weight and output activity level. It's clear now how the stronger the connection, the more it increases harmony level of the net:

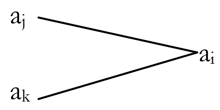
34)

a.



$a_j=0.2$; $a_k=0.2$; $w_{ij}=+2$; $w_{ik}=-1$
$Netinput_i=(0.2*2)+(0.2*-1)=0.2$
$H_{ij}=0.2*2*0.2=0.08$
$H_{ik}=0.2*-1*0.2=-0.04$
$H_{net}=0.08+(-0.04)=0.04$

b.

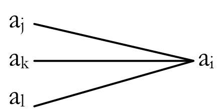


$a_j=0.2$; $a_k=0.2$; $w_{ij}=+8$; $w_{ik}=-1$
$Netinput_i=(0.2*8)+(0.2*-1)=1.4$
$H_{ij}=0.2*8*1.4=2.24$
$H_{ik}=0.2*-1*1.4=-0.28$
$H_{net}=2.24+(-0.28)=1.96$

In order to improve network harmony level it's then better to respect the strongest connections, and this, given the fact that connections can state conflicting demands, turns out to be a crucial point. An important difference with the conflict solving strategy of OT is that, given the numerical nature of the connections of neural networks, a set of light weight connections can "conspire", adding up their values, and "defeat" a heavier connection (here the winner is the one who assign positive or negative sign to the activity level of the output:

35)

c.



$a_j=0.2$; $a_k=0.2$; $a_l=0.2$
$w_{ij}=+6$; $w_{ik}=-4$; $w_{il}=-4$
$Netinput_i=-0.4$

$H_{ij}=-0.48$
$H_{ik}=0.32$
$H_{il}=0.32$
$H_{net}=0.16$

a_j, a_k and a_l represent inputs, a_i the output and w the weights; Netinput is the activity level of output unit, H_{ij}, H_{ik} and H_{il} are the harmony values of the single connections and H_{net} is the overall harmony value.

To maximize network's harmony, then, we have to find the best weight tradeoff, i.e. a weight configuration that allows optimal constraints' satisfaction. Now, given that input and output configurations correspond to input and output representations, the harmony level of the network that maps these representations has to be interpreted as the measure of the well-formedness of output representations, i.e. of how much they satisfy most important constraints: given an input, a network that aims to harmony maximization produces the optimal output representation. The similarity with OT is now straightforward: even if one handles symbols and the other (numerical) activity streams, in both approaches the input has to pass through a set of constraints/connections in order for the best output representation to emerge. It is important to stress again that, furthermore, connections are soft constraints, that satisfaction of some of them imply the violation of others, and that output representations are the one that best satisfy the most relevant constraints: in other words, emerging representation is not the well-formed one, but the best-formed, the optimal one.

The next stage of generative phonology "evolution", which can benefit from, as has been shown, the previous proposals, is of course OT, but you already know it…