Frog Leaps and Human Noises

An Optimality Theory Approach to Cultural Change

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December 2001

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Abstract

Optimality Theory came into being during the last decade of the 20th century as a linguistic theory seeking to explain language phenomena in a rather revolutionary way: grammars would no more consist of inviolable strict rules to be learnt by heart, but rather are to be thought of as sets of violable constraints which determine optimal output types among competing ones. In this paper an attempt is made to extract this explanatory mechanism from the linguistic field and implement it in decision-making areas involving cost and efficiency. This attempt is substantiated by the construction of a model which evaluates sets of candidate outputs in terms of optimality in particular situational settings. Considerable interest has been given to the flexibility of the model, as to formalize quite diverse aspects of human behavior, all of which share in common a strong disposition towards economy constraints and effort versus utility equilibria. Individual preferences, as well as previous experiences, are crucial factors for the evaluation of candidates which takes place under a combination of quantitative methods along with standard Optimality Theory techniques. Optimal outputs in turn, constitute behavioral patterns and eventually lead to cultural change. The concept of violable constraints is shown to resemble common-sense procedures in decision-making, thus the model functions in both a theoretic and an operational perspective.

Acknowledgements

This thesis was written between September and December 2001 in Amsterdam under the supervision of Henk Zeevat.

I 'm deeply indebted to Henk for his precious support, continuous interest and restless involvement in the construction of the model. Some of the most critical parts of it, including the novel conceptions of Meta-Constraint and Double Lines, would have never been disclosed without Henk introducing the original ideas. I feel lucky, to say the least!

The ILLC in Amsterdam is a fertile environment for academic work. I would like to thank Dick de Jongh for offering me, in the first place, the chance to study and work in such an environment, Ingrid van Loon for her friendly support throughout this year and Remko Scha for our meeting by the Singel canal discussing Marxism and information-society. I have benefited from all of my teachers here in Amsterdam; in particular I express my thankfulness to Karen Kwast, Martin Stokhof and Michiel van Lambalgen . It seems that I will never forget Michiel's sentimental closing remarks during the final lecture of last year's "Foundations of Mathematics: finite and infinite" course.

Boudewijn de Bruin had undertaken the task to initiate me to the logical world and more than a tutor he turned out to be a friend. Thanks for both.

A special note has to be made for people in my home University, the Department of Communication and Media Studies of the University of Athens. Michalis Meimaris' wise pieces of advice and Spiros Moschonas' frequent e-mail correspondence have been a valuable resource of encouragement and inspiration.

My love and gratitude goes to George Theocharis for being a real friend.

This thesis is dedicated to my mother Tassie and my wife Claire.

A.P.G.

Amsterdam, December 2001

Chapter 1

Introduction

"Optimality" is both an ambiguous and a promising word: it implies that the solution given to a certain problem satisfies the needs and limitations of the case. It does not only satisfy those needs, but, in addition, an optimal solution claims to be the best candidate out of all possible alternatives. Still, a high degree of ambiguity is hidden behind this at first sight simple and innocent notion; for what is best, optimal or even plainly satisfactory is always a matter of the evaluating criteria. If one does not bear in mind explicitly specified criteria for whatever problem under discussion, then one should not refer to optimal solutions, at least in cases where optimality is at the same time a matter of rational, inter-subjective definitions.

Standard linguistic Optimality Theory overthrows this kind of ambiguity employing a mechanism for evaluation which fulfils the quest for differential criteria. The set of violable constraints, always present in OT evaluations, has to be thought of as a means of justification for the characterization of outputs as optimal or not. Therefore, the overall input - output machinery of OT, with respect to the notion of optimality, is neither ambiguous, nor arbitrary, and this fact explains both the success of OT in the field of linguistics as a rational explanatory theory within the paradigm of generative grammar and the attempt to transfer and use parts of the OT device into wider decision and evaluation related frameworks. The pursuit of well-established, rational and widely acceptable judging criteria is reasonably a constitutive part of common-sense decision-reaching processes and it seems that the conception of a set of violable constraints as such criteria, integrated in a self-contained input - output theoretic device, provides an acceptable solution within the common-sense evaluation and selection framework. This is the thesis defended in the present paper.

Therefore, the purpose of this thesis is to answer the criterion-quest problem by showing the close relation between OT and common-sense as decision-making and selective processes, and to propose a suitably modified device for the adjustment of the violable constraints concept into non-linguistic areas. Consequently, the task involves to extract, modify and adapt the standard OT mechanism from the linguistic field and demonstrate ways of implementing the generalized conceptual scheme in particular cases. This is accomplished by means of a functional model which simulates the proposed adapted mechanism. The core argument of the thesis is the model itself, for it both resembles the OT evaluation process in an abstract way, thus formalizing the general case in accordance with standard OT, and determines optimal outputs with respect to unambiguous procedures, such as the employment of the modified set of constraints, thus answering the common-sense question for clearly defined criteria. The model aims to be applicable in a wide range of diverse cases and especially within the area of social sciences. As long as the model is primarily concerned with human behavioral patterns, which in turn accumulatively account for changes in the cultural environment, cultural change is explained as the result of optimal human behavior; apparently, optimal in this case signifies no more than the fact that the specified behavior has been selected as the optimal choice among the members of the set of all possible actions with regard to the particular situational setting, according to the adapted mechanism of OT as described by the model.

The construction of the model is followed by simple example cases from quite different areas, in order to demonstrate the diverse field of implementation. In particular a decision-reaching problem regarding investment policy in an economy facing a leapfrog growth alternative, as well as the case of marking human objects in language in relation to the articulatory effort needed to produce the additional marking sound\noise, have been implemented as instances of the operational and the theoretic aspects of the model respectively. It is worth mentioning that these characteristic example cases in fact account for the somehow symbolic title of this paper.

The structure of the thesis has briefly as follows:

Chapter 2 sets the historical background of the investigation. Starting off with the twofold of the principle of minimum effort along with the moral values of classical utilitarianism, the question of how to measure utility is readdressed once again. The relation of optimal behaviors, i.e. behaviors which are the optimal outputs of the model, with behaviors that maximize utility, defined in terms of welfare or happiness as it this the classic approach, besides the historical relationship, brings also to light the moral aspects of the issue.

The notion of Pareto-optimality is examined in some more details, for, besides its apparent lexical relation with Optimality Theory which could be due to coincidence (though this turns out not to be the case from a distant perspective), it has been a widely used evaluation criterion in economics and political theory throughout the 20th century, i.e. it has been one of the main criteria in areas where optimal decision-making is of topmost importance.

Chapter 3 is a brief introductory overview of the fundamentals of Optimality Theory in order to make clear the similarities, as well as the differences, with the model developed in here. The main focus is of course on the conceptual parts of the theory and not on the particular linguistic techniques, for it is the rationalization scheme of OT which is actually modified and employed in the abstract model construction.

Furthermore, chapter 3 includes, in the form of examples already established elsewhere, such as the robots example, previous attempts that are similar in spirit to the present investigation, the common link being the application of the OT evaluation device in non-linguistics fields. The same goes for the significant parallelism drawn between game theory and bi-directional OT in [De&vR]. All these examples in fact argue in favor of the nuclear thesis defended in this paper: there is a common suspicion that the mechanism of OT accurately mirrors common-sense procedures for decision-making, and this is made evident especially in the case of the parallelism with game theory.

Chapter 4 describes the model in all its details. In turn, it is divided in two main subchapters: in the first, the motivation behind the model is presented, as well as an outline of the model's mechanism following the respective flow-chart; in the second, all the elements of the model are examined one by one in terms of both their functional role and their conceptual significance. In this part novel modifications to the standard OT theoretic equipment are introduced, the most important of which being the following:

1. The Meta-Constraint concept.
2. The Double Lines evaluation steps.
3. The launching of numeric values for candidate outputs.

4. The acceptance of both negative and positive values for constraints.

Chapter 5 consists of three example implementations of the model. In all cases the author substitutes the decision-making subject (i.e. the subject supposedly running the model) for purposes of demonstration. Epigrammatically, the example cases are:

1. The economic case of investments in an underdeveloped economy.
2. The grammatical case of marking human objects.
3. An everyday life case concerning decision-making with respect to a limited set of alternative solutions.

These examples are in general simplified, especially under the light of the fact that no real data are provided as far as numeric constraints are concerned, and their main purpose is to exhibit the functionality of the model in actual cases.

Epilogue concludes the thesis. Emphasis is given to the flexibility of the model and its relation to standard OT and common-sense. A final note is made with respect to iterative instances of the model in which optimal outputs of the antecedent instance serve as inputs for future instances; this is the conclusive "loop remark", figuratively signifying the underlying idea of continuous cultural change.

Chapter 2

What Happened to Utilitarianism?

2.1 Absolute and Relative Utility

Utilitarianism, as a term and as a moral theory, is attributed to English philosophers of the late 18th and the first half of the 19th century. The most prominent among those philosophers were J. Bentham and J.S. Mills. Still, utilitarian in spirit theories are to be found long ago before that time; Mills, himself traced the roots of utilitarianism back to Aristotle, though a closer association than the one he actually suggested with hedonism theories following the rise and fall of the school of Epicureans would have been more appropriate.[1]

English utilitarianism is based on the principle of utility, originally formulated by J. Bentham:

> "By the principle of utility is meant that principle which approves or disapproves of every action whatsoever, according to the tendency which it appears to have to augment or diminish the happiness of the party whose interest is in question; or, what is the same thing in other words, to promote or to oppose that happiness. I say of every action whatsoever; therefore not only of every action of a private individual, but of every measure of government. (...)
> By utility is meant that property in any object whereby it tendes to produce benefit, advantage, pleasure, good, or happiness (all this in the

[1] Cf.: "Mill was more willing to acknowledge as utilitarian precursors some thinkers who were doubtfully utilitarian at all. He described Aristotle as a "judicious utilitarian" (...) Granted that he was judicious, was he a judicious utilitarian, however? The answer is that he was not." [RMi&Be, pp.20 - 21]

> present case comes to the same thing) or (what comes again to the same thing) to prevent the happening of mischief, pain, evil, or unhappiness to the party whose interest is considered; if that party be the community in general, then the happiness of the community; if a particular individual, then the happiness of that individual."[2]

Utilitarianism turned out to be one of the most influential theories in moral philosophy, probably due to its relation with common sense and its appeal to collective happiness in terms of the principle of majority. Equally important is the impact of utilitarianism in practical aspects of the social sciences and, in particular, of political economy. This sharp and significant distinction between the purely theoretic facet of utilitarianism and its practical applications is eloquently drawn in [Albee]:

> "The technical use of the term Utilitarianism (...) has never become entirely divested of certain associations connected rather with the ordinary meaning of the word "utility" and with the supposed practical applications of the Utilitarian theory, than with the essential logic of the theory itself. (...) Bentham and James Mill, (...) were much more interested in the supposed practical applications of the theory of Utility than in the theory itself considered merely as belonging to Ethics as one of the philosophical disciplines."[3]

It is exactly the practical applications of utilitarianism that are of interest for the purposes of the present investigation, for they set its historical background. As far as the process of reaching optimal decisions -either individually or collectively- is concerned, there seems to be an underlying consensus in western thinking in favor of the principle of utility as the essential tool for evaluating the degree of optimality of alternative solutions to a particular practical problem. The principle of utility, within the framework of instrumentalism (and not of ethics), may be assumed to be the common philosophical background in theories of political economy all throughout modernity.[4] But the practical aspect of utilitarianism

[2]Bentham, J.: "An introduction to the Principles of Morals and Legislation" in [RMi&Be, pp.65 - 66]

[3][Albee, pp. xv - xvi]

[4]This is argued to be true even for theories preceding the explicit foundation of English utilitarianism. Adam Smiths' invisible hand can be thought as an imaginary entity which operates in accordance with the principle of utility (*The Wealth of Nations*-1776 was published more than a decade before English utilitarianism's allegedly foundational essay, namely Bentham's *An introduction to the Principles of Morals and Legislation*-1789 was published, although, according to its preface, Bentham's text had been written sometime before 1780). Utilitarianism, though questioned for its philosophical implications as

posed a severe question to its proponents and their followers: how is utility to be measured?

2.2 Measuring Utility

Bentham indeed provided the theoretic framework for the answer to the above question. His recipe appealed to four "circumstances" in order to determine the value of a pleasure or pain: (a) its intensity, (b) its duration, (c) its certainty or uncertainty, and (d) its propinquity or remoteness.[5]

In turn Bentham's recipe gave rise to what came to be known as the theory of absolute utility: the idea that utility may be precisely measured and, using the principle of utility as a criterion, optimal decisions could be effectively reached. This theory was shortly proven to be a mere fallacy, for no such thing as a measurement unit for utility could be established. What unit may be used in order for one to measure the pleasure of, say, eating a candy? Consequently, the theory of absolute utility was abolished in favor of the more flexible theory of relative utility which set the basis for modern micro-economics' consumer theory and turned out to be a rather stable one: indeed, claims the theory of relative utility, there is no way for utility to be accurately measured; still different utilities may be ranked hierarchically with respect to each other. The fundamental assumption here is that, although one may not estimate how much pleasure is to be found in eating a candy, one may determine whether there is more or less pleasure in eating a candy than it is in, say, eating an apple or in watching one's favorite program on television. Therefore, this hierarchy of relative utilities provides the data needed for the practical applications of the principle of utility.

A closing remark on this brief historical overview of utilitarianism, regards different (social welfare) utility functions which have been proposed in the course of the years following the foundation of the theory in order to account for the collective preferences of a community. These social welfare utility functions are supposed to determine optimal distributions of goods (widely perceived as including immaterial goods as well) according to different moral principles, all of which

in [Rawls], dominated the practical aspects of western economic theories, at least as a general, widely acceptable desired goal, and to a certain extend may be thought to underlie, suitably modified, even modern formulations of economic theory within the paradigm of (Galbraith's) welfare economics.

[5]The problematic account of utility measurements is made clear if one tries to follow Bentham's recipe in every detail. The whole logistic-like process described by Bentham depends essentially on the values of pleasure or pain. Yet, when it comes to the actual measurement of these values one is confronted with the lack of an appropriate measure. See: Bentham, J.: ibid., pp. 87 - 88.

depend on the practical aspect of utilitarianism as far as utility *per se* is concerned:

- Bentham's classic utilitarian function:

$$W(u_1,\ ...,\ u_n)\ =\ \sum_{i\in\mathbb{N}}^{n} u_i$$

  This is a social welfare utility function which states that the welfare of a community is equivalent to the sum of the welfare of all n members of the community.

- Weighted sum of utilities:

$$W(u_1,\ ...,\ u_n)\ =\ \sum_{i\in\mathbb{N}}^{n} a_i\ \times\ u_i \quad (a_i\ >\ 0)$$

  This is a social welfare utility function which states that the welfare of a community is equivalent to the sum of the weighted welfare of each one of of all n members of the community; the weight accounts for differences in the significance the welfare of each member has for the community.

- Rawls' social welfare function:

$$W(u_1,\ ...,\ u_n)\ =\ \min\{u_1,\ ...,\ u_n\}$$

  This is a social welfare utility function which states that the welfare of a community is equivalent to the welfare of its least privileged member.

These example cases, although widely diversified in terms of ethics -the welfare of the least privileged person which determines the social welfare on Rawls' account, has a relatively negligible impact on Bentham's account-, all share in common the basic conception of the practical aspect of utilitarianism: individual welfare states described in terms of utility. Obviously there are quite distinct moral values underlying these functions. Yet, the pursuit of happiness is commonly presupposed to govern individual goals and this is implied to be a common-sense assumption.

This being the case, the present investigation is to be thought of as following the classic utilitarian tradition since it incorporates the utilitarian common-sense assumptions, and in particular the pursuit of happiness as a reasonable individual goal and the principle of minimum effort as an overall, equally reasonable, rule governing individual preferences and behaviors. Still, the present attempt is to be distinguished from the ethical, or even more from the deontological aspect of utilitarianism. For this attempt aims only in determining optimal behavioral patterns from alternative ones in a mechanistic manner under the above mentioned assumptions. It makes no claim whatsoever as for the moral significance of the results; i.e. it is not claimed that the optimal outputs of the model *should be* enforced as being in accordance with the moral values of utilitarianism.

2.3 Pareto-Optimal Equilibria

The notion of Pareto-optimality, named after the Italian economist Vilfredo Pareto of the late 19th century, has been widely employed in decision theory in order to evaluate different distributions of goods with respect to an initial distribution.[6] In addition to the above mentioned historical background of the present investigation, the notion of Pareto-Optimality is briefly examined as a characteristic type of criterion used to determine optimal solutions within the practical utilitarian framework.

A Pareto-optimal solution is one in which no further interactions between the participants of the initial distribution may lead to an increase of the happiness of any one of them, without at the same time decreasing the happiness of some other. In an example: Let an initial distribution in a dinner table be such that on the one side of the twelve chair table sit 4 smokers and 2 non-smokers, and on the other 5 non-smokers and 1 smoker. The practical utilitarian assumptions underlying Pareto-optimality are that: (a) smokers prefer to sit next to smokers and the same holds, inversely for non-smokers, and (b) the happiness a smoker enjoys from sitting next to a smoker is equal to the happiness a non-smoker enjoys from sitting next to a non-smoker. Then, a mutual trade of places between one of the non-smokers from the side of the table where the majority is smokers and the smoker from the non-smoking side, so to speak, would increase the happiness of both (and the people next to whom the traders were previously sitting) and would not decrease the happiness of anyone else. This is exactly the type of interaction (trade, exchange) the Pareto model employs in order to reach optimality. In the above example, after the trade the distribution has reached a Pareto-optimal equilibrium; for no further interactions may increase the happiness of anyone, without at the same time decreasing the happiness of someone else. If the second

[6] The initial distribution has to be thought of as the starting point for the evaluation process and is assumed to be given in advance. This is much like the "original condition" found in the social contract type of political theories, as in [Rawls]. Therefore it comes as no surprise that modern formulations of the Rousseauian social contract theory, accept to a large extend Pareto-optimality as a criterion for the evaluation of alternative distributions as optimal or not. See [Rawls, subchapter 2.12, "Interpretations of the second principle"]

non-smoker from the smoking side is to trade places with someone on the non-smoking side of the table, then the latter would be a non-smoker whose happiness would be negatively affected by this trading.

The notoriously difficult point with practical applications of Pareto-optimality, which, nonetheless, is one easily overlooked, is that, theoretically, there is an infinite number of Pareto-optimal distributions some of which are rationally assumed to be far less than optimal in everyday's language use of the term. E.g.: Let the initial distribution be such that all the wealth of planet Earth is possessed by a single human being. Unfortunately for the rest approximately 6 billion inhabitants of the planet this **is** a Pareto-optimal equilibrium. No interaction may increase the happiness of any human without at the same time decreasing the happiness of the only possessor. For, and again this is the utilitarian assumption, even if the possessor is deprived from only one cent, her happiness will decrease.

Beside the difficulty in practical applications, Pareto-optimal distributions are in principle desirable and worth targeting goals. If certain interactions, would be the common-sense argument, increase the happiness of some people without affecting the happiness of others, why not employ them? Indeed, this is quite a valid argument and explains why Pareto-optimality has been so widely accepted in various fields of the social sciences. Furthermore, due to the conceptual clarity of the notion, Pareto-optimality has undergone various task-specific modifications and has been effectively applied with respect to such diverse notions as "the important artificial intelligence concept of reasoned assumptions" (in [Doyle]) and belief representations, as in [Schul].[7]

Pareto-optimality has been briefly reviewed as an archetypical example of criterion employed in evaluation processes. Though Pareto-optimality refers to distributions, thus having no common field of application with the present model (that is, one may not substitute the other), they both share their motivation, to be found in the quest for common-sense evaluating criteria. Be that the equilibrium of conflicting utilities, or a set of violable constraints, such criteria are supposed not to conflict with the basic assumptions of practical utilitarianism and purport to determine optimal state of affairs, either with respect to distributions of goods, or with respect to a set of alternative solutions.

[7] Cf. for example: "Roughly, Pareto-minimal belief revisions are those that cannot be improved by adding fewer beliefs without giving up more, or by giving up fewer beliefs without adding more." [Schul, pp.1 - 2]

Chapter 3

Optimality Theory

3.1 Overview

Optimality Theory was initially introduced by Paul Smolensky and Alan Prince in the end of the 20th century and soon became highly acclaimed, at least by some members of the linguistic academic community. Originally OT concerned the field of phonology, but in less than a decade it has expanded and equally revolutionized the fields of syntax and, more recently, semantics. For no discipline or theory considered to be alive and developing may be claimed that it is petrified and not subjected to further modifications, but OT, being such a recently developed theory reflects a relatively higher rate of growth and expansion than average; moreover, new ideas and fields of application are constantly added in OT's stock-account indicating, if not anything else, at least the fact that the original conception has proven to be a rather inspiring one. Besides its horizontal, so to speak, development across most on the fields along which language phenomena are being studied, OT expands also vertically, thus accounting for a higher degree of explanatory adequacy.

The basic lines along which OT conceptually has to be distinguished from previous linguistic theories within the generative grammar paradigm are the following:

- Linguistic forms are connected and evaluated with respect to each other, according to a set of constraints, as opposed to single-feature separated evaluations according to certain rules.
- Constraints in OT, conceptually loosely corresponding to the *rules* or *principles* of traditional grammars, are violable, as opposed to the rules assumed by previous theories which are considered inviolable.

- Optimal outputs according to OT are those surface language forms which best satisfy the system of constraints among other competing candidates, as opposed to "right" and "wrong" outputs of other approaches.[1]

The OT device which accomplishes the above mentioned tasks is an input - output mechanism integrating an evaluation function. In terms of features the OT device comprises the generator *GEN*, which is a function generating candidates for every input, the (universal) set of constraints which are (language-particular) hierarchically ranked, and the evaluator (Eval) which determines optimal outputs with respect to the set of constraints.

Descriptively, the basic idea behind OT is that language forms emerge as the optimal outputs among competing ones with respect to a set of (antagonistic with each other, in principle) constraints. The set of constraints, though the most important, is just one of the three basic components of OT in terms of the basic features, the other two being the Generator and the Evaluator. These formal elements in turn are in compliance with a set of corresponding assumptions:

> "First, a set of inputs is assumed. For each input, **Gen** creates a candidate set of potential outputs. The second assumption is that from the candidate set **Eval** selects the optimal output for that input. The third assumption is that there is a *language particular* ranking of **con**straints from an universal set of constraints."[2]

The set of constraints is considered to be a universal one and, consequently, is assumed to be part of our internal linguistic knowledge. Therefore, OT depending crucially on the nature of constraints must be thought of as a theory within the framework of generative grammar and a considerable newcomer in the line of theoretic candidates for the explanation of linguistic phenomena. In fact, it would be no exaggeration, at least as far as the study of language is concerned, for one to describe the emergence of OT as a paradigm shift in the terms of Kuhn from previous linguistic theories.

An example case illustrating the technical part of the above overview concerns hiatus avoidance (the avoidance of two syllabic peaks in a row).[3]

It is a common feature of languages the attempt to avoid hiatus, but they differ as to the extend to which they tolerate hiatus and with respect to the techniques

[1] More formally, the OT optimal-candidate determination criterion reads as follows: "A candidate w is considered to be optimal iff for each competitor w', the constraints that are lost by w must be ranked lower than at least one constraint lost by w'." [Blut1, p.8]

[2] [Blut2, Chap.1], emphasis and italics in the original.

[3] This example as a whole in [Fa&Fé, pp. 19 - 20]

used in order to "repair" unallowed hiatuses.

> "An output structure which avoids hiatus can be obtained in different ways. Frequent strategies are vowel deletion, consonant epenthesis, and glide insertion."[4]

In the case examined in the example hiatus avoidance in French is achieved by the strategy of vowel deletion. The constraints according to which the Eval functions are:

- The faithfulness constraints DEP and MAX. Faithfulness constraints require identity between input and output. DEP is interpreted as "no epenthesis of segments and features" and MAX is interpreted as "no deletion of segments or features".
- The markedness constraint NOHIATUS. Markedness constraints require unmarkedness of the output, although, as argued in [Fa&Fé], it is not always clear what is unmarked and consequently markedness constraints rely heavily on the results of markedness theory. NOHIATUS is interpreted as "avoid hiatus -(avoid syllabic peaks in a row)".
- The ranking of constraints depends on the way each language resolves the issue of hiatus. In cases that the issue is not resolved at all the NOHIATUS constraint is ranked at the end of hierarchy, being the least significant of all. If hiatus is to be resolved in any way the NOHIATUS constraint is placed on the top of the hierarchy signifying the relative importance of hiatus avoidance for the particular language. The specific strategy employed in order for hiatus avoidance to be achieved is determined by the ranking of the faithfulness constraints. In the case of French, which is examined in this example the DEP constraint overrides MAX in the hierarchy signifying the preference of the vowel deletion strategy. An inverse ranking of these two constraints would favor the consonant epenthesis strategy.

The evaluation technique of OT is diagrammatically depicted in evaluation tableaux, which are matrices including specific features and symbolizations. In particular the standard OT-tableau has the following features:

- The candidate outputs in no particular order in the left column of the matrix.
- The constraints positioned in hierarchical order of significance from left to right in the top row of the matrix.

[4] [Fa&Fé, p.19]

- Evaluation signs: the asterisk which indicates a violation of the constraint in the column of which it appears by the candidate output in the respective row (i.e. an asterisk in $cell_{ij}$ of the matrix indicates a violation of the constraint j by candidate output i). Analogously an asterisk-exclamation combination indicates a fatal constraint violation (i.e. one that expels a certain candidate from further consideration).
- Gray-shaded cells which indicate that the content in them is unimportant for deciding the optimal output.
- The pointing-hand icon which points out (literally!) the optimal candidate.

Therefore, in order to resolve in terms of OT the above described example concerning the avoidance of hiatus for an input case such as [/le/+/éléphant/] in French, the following evaluation tableau has to be constructed:

Input: /le/+/éléphant/

Constraints → **↓ Outputs**	NoHiatus	Dep	Max
☞ l' éléphant			*
le eléphant	*!		
le teléphant		*!	

Candidate output "l' éléphant" turns out to be the optimal one, though it violates the Max constraint by deleting vowel e from the article le. Still, due to the ranking of constraints is the optimal one, for all other candidates violate higher ranked constraints. Candidate output "le teléphant" violates the Dep constraint for the phenomenon of epenthesis takes place in the form of the consonant t which has been added and candidate output "le eléphant" obviously violates the NoHiatus constraint for two syllabic peaks take place in a row. This example, besides demonstrating the standard OT technique, also makes clear that the ranking of constraints is a key-feature of the OT evaluating mechanism.

3.2 Robots, Calendars, Games

Up to the present day, there have been only a few attempts for the application of OT's basic mechanism in cases that fall outside the field of linguistics. Most of them come in the form of educational examples and should be regarded rather as non-linguistic illustrations of the OT paradigm than actual applications.

One such illustration, which should be also mentioned as the seed of inspiration for the work at hand, concerns the three laws of robotics as stated by Isaac Asimov in sci-fi classic *I, Robot*. The laws of robotics, in the sense of rules, are perceived for the purposes of the illustration as corresponding to the OT set of constraints. Thus the constraints and their interpretation in hierarchical order for this example have as follows:[5]

1. Name: *INJURE HUMAN
   Interpretation: A robot may not injure a human being, or through inaction, allow a human being to come to harm.
   Ranking: 1 (front rank, leftmost position in the tableau)
2. Name: OBEY ORDER
   Interpretation: A robot must obey the orders it takes from human beings.
   Ranking: 2 (middle rank, middle position in the tableau)
3. Name: PROTECT EXISTENCE
   Interpretation: A robot must protect its own existence.
   Ranking: 3 (back rank, rightmost position in the tableau)

Accordingly, an input story like *Human says to Robot: "Kill my wife"* gives rise to an OT-like evaluation process of alternative behavior scenarios regarding the Robot's response to that particular order. These scenarios are to be thought of as the members of the set of candidate outputs. Therefore, an OT evaluation tableau may be constructed:

Constraints → **↓ Outputs**	*INJURE HUMAN	OBEY ORDER	PROTECT EXISTENCE
R kills **H**'s wife	*!		
R kills **H**	*!	*	
☞ **R** does not kill anyone		*	
R kills himself		*	*!

The optimal output is shown to be candidate 3 despite the fact that it violates the obedience constraint, as long as all other candidates violate more or higher ranked constraints. Different input stories would result in different optimal outputs as would have been also the case if some other ranking of constraints was

[5] This example illustration as a whole in [Blut1, pp. 3 - 5]

assumed.

In another, non-fictional illustration of the evaluating mechanism of OT the case of leap-years is examined. Here the rule to be reformulated in terms of constraints regards the frequency of leap years and reads as follows: *Leap years are those years divisible by 4, except centesimal years, which are common unless divisible by 400.* Therefore, the set of constraints contains the following members in hierarchical order:[6]

1. Name: DIV-400
   Interpretation: Years divisible by 400 have 366 days.
   Ranking: Position left to right: 1
2. Name: DIV-100
   Interpretation: Normally, years divisible by 100 have 365 days.
   Ranking: Position left to right: 2
3. Name: DIV-4
   Interpretation: Normally, years divisible by 4 have 366 days.
   Ranking: Position left to right: 3
4. Name: ALL YEARS
   Interpretation: Normally, years have 365 days.
   Ranking: Position left to right: 3

Candidate outputs take the form of years including a different number of days, and the evaluation process determines the optimal one according to the rule of frequency which has been transformed into constraints. The example tableau for year 1996 is the following:

Constraints → **↓ Outputs**	DIV-400	DIV-100	DIV-4	ALL YEARS
1996 had 364 days			*!	*
1996 had 365 days			*!	
☞ 1996 had 366 days				*

The OT evaluation mechanism "correctly" characterizes candidate output 3 as optimal, thus showing that 1996 was a leap year according to the rule which defines the frequency of leap years.

[6]The author of this illustration is Sten Vinker of the University of Stuttgart. Source URL: http://www2.rz.hu-berlin.de/linguistik/institut/syntax/sl/ot.htm

Both these examples clearly illustrate the wide range of applications the OT device may have and its relation to common-sense evaluation processes; at the same time, carefully observed, they disclose the significant difficulties with which an attempt to extract the OT from the linguistic field may be confronted:

- The set of constraints, and more importantly their ranking order in these examples is readily given by the rule which has been transformed into constraints. In both cases the rule is external to the device and *ipso facto* determines the ranking of constraints. In the first case by the original formulation of the laws of robotics and in the second by the relative scarcity of years divided by 400, as opposed to years divided by 100 and so on up to normal years. Yet, an OT-like model for optimal decision-reaching should not rely to external sources for the ranking of constraints, for, then, it would be a task-specific mechanism, i.e. inadequate to capture the general case as the model-building abstraction requires.

- Analogously, the model should provide an explanation for the origin of the members of the set of candidate outputs. What distinguishes a candidate output from a similar item (with reference to the particular problem), which is not included in the set of candidate outputs? It should be obvious that a candidate output of the type "*Robot calls the police*" would not adduce much to the educational purpose of the first illustration; yet, in the case of a general model, an explanation has to be given as to whether such a behavior should be added or not to the set of candidate outputs.

- Finally, the inspiring character of the examples may give rise to over-optimistic expectations as far as the ability of such a model to handle more complicated cases is concerned, with reference to the type of the input problem which is not to be aforehand selected, but, instead, occurs as an arbitrary evaluation problem in the environment of the subject supposedly running the model.

Beside these demonstrative examples, a parallelism has be drawn in [De&vR] between bi-directional OT and game theory. In this case the direction of application is from game theory to OT and not vice versa; still, the parallelism is based upon the conceptual schemes for decision-reaching, to be found in both theories, in terms of optimal outputs in the case of OT and in terms of equilibria in game theory:

> "The ranking and judging of representations and meanings in optimality theoretic interpretation has a structure which resembles principles

> developed in the well-investigated field of Game Theory."[7]

As long as bi-directionality in OT refers to both the production and the consumption (to be identified with interpretation) of linguistic items, the issue is reasonably addressed in terms of conflicting interests between the participants of a language game. The economical aspect of a gain-loss equilibrium is shown to be closely related with the Gricean maxims, introduced in [Grice], at least in their reformulation as the Q-principle, which advices the speaker to say as much as possible in the attempt to reach her communicative goal and the I-principle which advices the speaker to do exactly the opposite (say no more than is needed). Therefore, it has been argued that the conflicting interests of the hearer and speaker in terms of the Q-principle and the I-principle may take the following game-theoretic formulation:

> "The principles can be seen as representations of rational goals of competing forces to *minimize their efforts*: The I-principle represents the *speaker's* goal to minimize the effort to *communicate* as much as possible, while the Q-principle can be seen to represent the *hearer's* goal to minimize his effort to *understand*."[8]

The formal analysis of the case of bi-directional OT as an application of game theory leads to conclusions favoring the attempted parallelism and suggesting further investigations concerning the conceptions, as well as the evaluating mechanism of OT:

> "Optimality crucially involves both the speaker and the hearer, conceived as rational agents with possibly opposing preferences. An optimal interpretation of a sentence can thus be seen as the result of (hypothetical) negotiation between two players who, with their particular beliefs and desires, engage in a communication game."[9]

What the example illustrations, as well as the game-theoretic definition of bi-directionality, are supposed to reveal is a common underlying belief in the explanatory potential of Optimality Theory. In this sense they may be thought of as arguments in favor of attempts to employ the OT device in non-linguistic areas, such as the investigation undertaken in here, or, in a wider perspective, in favor of a parallelism with common-sense, drawn upon the quest for optimal solutions.

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[7] [De&vR, p.9]
[8] [De&vR, p.7], italics in the original.
[9] [De&vR, p.25]

Chapter 4

The Front-Rank Model

4.1 The Explanatory and the Operational Perspective

4.1.1 Motivation

The Front-Rank Model is a detailed, procedural description of the evaluation scheme, originally found in standard linguistic Optimality Theory. The model owes its name to the fact that the topmost constraint, the one to be placed in the front rank, plays a crucial role in determining optimal outputs. Of course, the interesting part emerges in cases when the combination of cell values for candidate outputs and constraint ranking overcomes the superiority of the top level constraint and the results are significantly different from the ones yielded by the top constraint only. In the majority of cases, however, at least with reference to the testing examples which were examined during the construction period, the model favors an advanced role for the front-rank constraint.

The motivation for the construction of the model originates from the similarities in OT's evaluation process and common-sense methods for decision-reaching. Assuming that common-sense methods involve some kind of pros and cons balance for alternative solutions, the question regarding the criteria according to which pros and cons are estimated is a critical one; this is answered by the set of constraints and, accordingly, common-sense's advantages - disadvantages schematically correspond to the values each constraint-candidate combination receives in the model. In terms of a motivational question the model aims to answer the organizational part of decision-reaching procedures in cases of multiple constraints (to be identified in this context with evaluating criteria) of varying significance.

The theoretic motivation of the model is rather modest: granted the adequacy of the OT mechanism for the explanation of linguistic phenomena, the model only aims to draw attention on the non-linguistic applications this mechanism may have, and, suggest it as a well-organized evaluation scheme for optimal selections among alternative, competing candidates. Therefore the development of the model, with respect to its motivational background, takes place along the following axes:

- Generalizing the OT paradigm in a cross-discipline direction, favoring the integration of quantitative methods with OT's violate/kill technique.
- Drawing a framework for the study of decision-reaching processes, under the assumption concerning the similarity of OT's constraint-based method with the common-sense advantages-disadvantages balance.

4.1.2 Homo-Economicus

The FR-model is not an alternative to standard decision-making models inspired by economic theory; rather it is a hybrid and psychologically plausible approach to decision-reaching, inspired by OT. The differences may be traced with respect to a decision-making example, much like the implementation demonstrated in 5.1 below, which follows the economic theory modelling scheme.[1]

Suppose a farmer owns 10 acres of land and faces alternative combinations of growing wheat and potatoes. The initial wheat-potatoes combinations space is shown in diagram 4.1. All points in the grey-shaded area corresponding to pairs of wheat-acres and potatoes-acres are attainable alternative solutions to the farmer's decision-reaching problem.

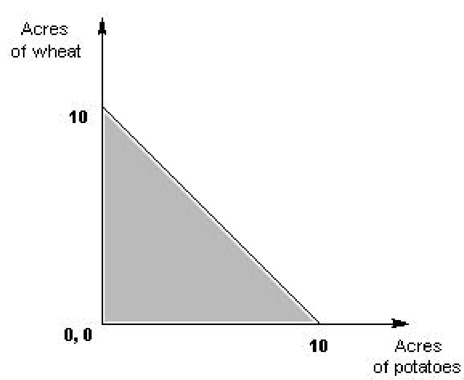

Figure 4.1: Wheat - potatoes combinations space without constraints.

[1]This example as a whole in Papadimitriou, C.H.: *Turing* (Greek translation A. Sideri), Livanis, Athens 2000, pp. 251 - 257.

Furthermore, suppose that the farmer is confronted with a labour constraint, stating that the labour supply conditions during the harvest period will be such that no more than 5 acres of wheat could be effectively reaped. Thus the wheat-potatoes combinations space is limited only to solutions including no more than 5 acres of wheat. This is the case shown in diagram 4.2:

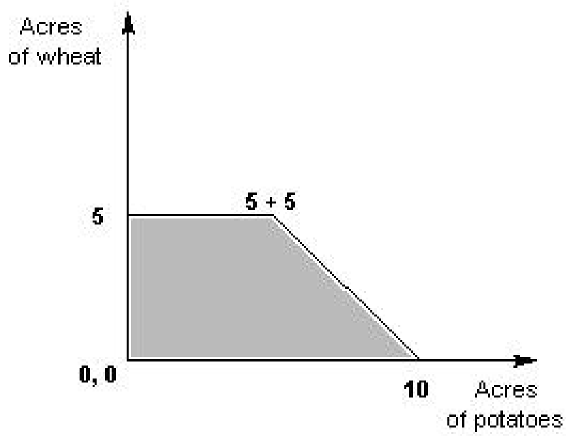

Figure 4.2: Wheat - potatoes combinations space under the labour constraint.

Finally, suppose that another natural constraint is posed to the farmer, regarding irrigation; e.g. assume that every acre of wheat demands 3 cubic feet of water per day, whereas every acre of potatoes demands 10 cubic feet of water, and the farmer has only access to 80 cubic feet per day. Thus, the wheat-potatoes combinations space is further limited to the grey-shaded pentagon of diagram 4.3. Assuming no further constraints, in order for the farmer to reach the maximum profit (i.e. the optimal) solution she/he needs to estimate the profit per acre of wheat and per acre of potatoes; in turn this estimation involves quite a bit of information, predictions with a high degree of accuracy and the consequent calculations, regarding labour costs, market prices etc. Let the sheer result of these calculations be such that each acre of wheat makes 10.000$ profit per year, and each acre of potatoes makes 8.000$ profit per year. This is the case shown in diagram 4.3:

The only thing left to be done for the farmer in order to reach the optimal

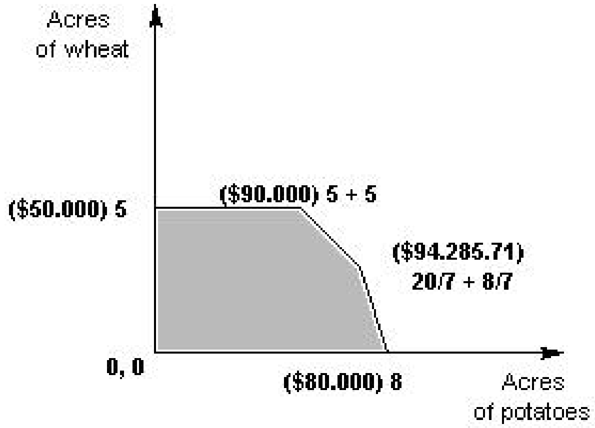

Figure 4.3: Wheat - potatoes combinations space under the labour and the irrigation constraints, including profit estimations.

solution under the utilitarian assumption of the maximum profit goal, is to calculate the profit gained by each wheat-potatoes combination. That is, for every point the gray-shaded area of diagram 4.3 to calculate the sum of the product of wheat-profit times wheat-acres plus the product of potatoes-profit times potatoes acres and select the maximum of these sums, which in the particular example is a profit of approximately 94.000$, gained from $7\,\frac{1}{7}$ acres of potatoes and $2\,\frac{6}{7}$ acres of wheat. [2]

Though rational and effective such a process may be, there have been some standard objections, common to all abstractions which are based on economic theory. Doyle offers a rather humoristic, yet accurately targeted objection against the assumption regarding the intellectual profile of the decision-making subject (e.g. the farmer):

> "Economists abstract from humans and other biological species and base their theories on a creature called *homo economicus*, or economic man. Economic men (and presumably economic women and children too) are marvels of consistency and calculation, but their powers of calculation are not relevant here."[3]

[2] Of course, algorithms have been developed which easily handle the computational part of this kind of selection problem. Indeed, such algorithms are of enormous help in more complex problems of the resources distribution family, as would have been the case if the farmer would have to consider more options than just the two presented in the example.

[3] [Doyle, p.2], italics in the original. It is worth mentioning that the context in which the author finds irrelevant the calculative powers of economic subjects is that of group decision making.

In the same line of reasoning, the following observations have been made with respect to the present day status of purely economic models of decision-making:

> "Dissatisfaction with the classical theory and attempts to replace the basic model of the rational man with alternative decision models are not new. (...) We have clear, casual, and experimental observations that indicate systematic deviations from the rational man paradigm. (...) The evaluation that very little has been achieved makes one wonder whether it is at all possible to construct interesting models without the assumption of substantive rationality. (...) The rationality of the decision-maker can be seen as the minimal discipline to be imposed on the modeler. Our departure from the rational man paradigm represents a removal of those chains. However, there are an infinite number of "plausible" models that can explain social phenomena; without such chains we are left with a strong sense of arbitrariness."[4]

Returning to the farmer example, the above quite legitimate objections may be practically observed in case (a) the farmer failed to gather all the relevant information and compute the optimal results, or, (b) granted an accurate computation process which presumably resulted in optimal outputs, still the farmer's final decision was not the maximizing profit one, accounting consequently for another instance of "casual observations that indicate systematic deviations from the rational man paradigm". Would that mean that the farmer is to be considered irrational?

As far as the first case is concerned, the above quote makes clear the situation. Indeed, "the marvel of consistency and calculation" subject is a rather strong assumption; yet in order to abolish it, one has to provide a proposal adequate enough at least to reach the same results as the classic approach and this has proven to be quite a difficult task. As far as the second case is concerned, one may observe that besides the external constraints posed on the farmer, her/his final decision could be motivated by factors not easily quantifiable which did not appear in the model at all. Reputation and tradition are such factors which may result in "irrational" decision making, though of course this is far from true. Assume, for example, that the farmer had been a potatoes producer for many years and her/his products were favored by the consumers for their high quality. Shifting from previous practices could have a negative impact on the farmer's ability to sell the new products, for she/he would have to convince the consumers that the new products are of equally high quality as the ones she/he had been pro-

[4] [Rubin, pp. 3 - 4]

ducing for years. Or, to make more clear the case, assume that the cultivation decision did not concern wheat and potatoes, but, instead, potatoes and cocaine. Current cocaine prices compared to the price of potatoes would favor the cocaine alternative under the profit maximization criterion; yet, a severe law-constraint accounting for the legal risk undertaken in the case of the cocaine alternative, would adequately explain in common-sense terms an "irrational" final decision favoring potatoes over cocaine. The question then to be addressed concerns the integration of non-easily-measurable constraints, so to speak, in the same framework as the standard economic constraints concerning effort and profit.

As mentioned before, the present model is not an alternative to economic-type decision models, although in terms of outputs one might at first instance suppose so. The reasons are the following:

- The FR-model is of relatively lower ambitions than economic models in both the practical and the theoretical point of view. Practically, it aims in organizing a step-by-step process for determining optimal outputs with respect to a specific situational setting and a corresponding set of candidates, as opposed to context-free correct results of economic models. In turn, this reflects the OT origins of the model: optimal outputs do not account for universally "right" and "wrong" candidates, but only for optimal outputs among competing candidates. Theoretically, at least in its present experimental status of development, it aims in drawing attention to the OT evaluation mechanism as a potential decision-reaching device, thus being more of an indicator and an argument in favor of a generalized cross-discipline OT than an actual instance of such a theory, as opposed to economic models assumed to be instances of the underlying decision theory.
- Though the FR-model directly addresses two essentially difficult issues of model building, namely individual preferences and qualitative constraints, which for the most part are ignored by economic models, this attempt comes at a high price: the model reflects optimal solutions only as far as the decision-making subject who is actually running the model is concerned (i.e. there is no way for one to run the model on behalf of someone else, due to the fact that critical parts of the model depend on the subject's preferences and background). This fact signifies the main difference with economic decision models: whereas, once given the data concerning the labour and irrigation constraints, as well as the estimations for market conditions, anyone could run the farmer example model and determine the optimal outputs, this is

not the case with the FR-model. One may rank the law-constraint according to its relative importance only for herself and not on behalf of others. Some people take high risks, and some do not.

4.1.3 A step-by-step process

Although in terms of the process employed there is no difference whatsoever between a theoretic and an operational usage of the model, there are diversified perspectives with respect to scopes, type of input problem and the decision-making subject (the subject which actually runs the model).

The explanatory usage of the FR-model concerns investigation tasks undertaken in order to explain certain phenomena, either observable or expected in theory. Thus it would be of no surprise if the input leads to decision-problems which correspond to behaviors already established, for the decision to be made refers to alternative explanations, i.e. the optimal output is the one which better explains the observed phenomenon.[5] In sum, the explanatory perspective involves:

- Input problems from both past and future behaviors.
- DM-subjects as investigators.
- Explanation seeking scopes.

The operational usage of the FR-model concerns decision-reaching processes in factual cases and, in general, for practical matters. The members of the set of candidate outputs are alternative behaviors none of which has yet been employed with respect to the particular situational setting and the DM-subject seeks to determine the optimal candidate in order to act accordingly. Therefore, the model under the operational perspective is to be thought as a formalization assistance for accessing optimal decisions, much like a guidance tool. In sum, the operational perspective involves:

- Input problems concerning future behaviors.
- DM-subjects as behavior selectors.
- Practical decision-reaching scopes.

The FR-model, taken as a device for the evaluation of possible solutions for particular problems, follows the standard input - output modelling scheme; the inner part of the mechanism processes the inputs in a step-by-step manner and

[5] An example implementation of the theoretic usage is demonstrated as Case 2: The Effort of Marking Human Objects in 5.2 below.

optimal outputs are computed according to an evaluation function. Although the evaluation function is an essential and proportionally large part of the model, including quite a bit of calculations -at least in comparison with standard OT- the procedural facet of the model is considered more significant. A simple way to support this characterization is by saying that alterations to the procedure suggested by the model may distort completely the final results, whereas, *ceteris paribus*, the impact of changes in the forms of calculation reflects a relatively lower degree of distortion.

The step-by-step process, as well as the outer shell and the feedback loop of the FR-model is shown in diagram 4.4 "The FR-model: Parts and process". The diagram depicts the parts of the model and their interrelation in terms of a linear flow-chart. In accordance with the diagram the mechanism of the model may be outlined as follows:

Inputs occur in the form of changes in the environment of the decision-making subject, most frequently as *needs* or *interests*. Inputs are always defined by a specific and detailed situational setting. For each input and the corresponding decision-problem a solution space, including all relative behaviors, is assumed. The standard OT generator (*GEN*) determines the set of candidate outputs from the solution space. The set of violable constraints, the most influential part of the OT machinery for the purposes of this model, mediated by the meta-constraint is converted to a significance hierarchy. The next step concerns previous experience which is integrated in the model as a parameter in the evaluation function involving available statistical measurements and predictions. The evaluation function, in its pure technical form, consists of the calculation formulae by which the cell values for all candidate outputs are computed. The final selection of the optimal outputs takes place in the evaluation tableau, by means of the Double Lines. Optimal outputs are the answers to the decision problem posed by the input.

Normally, optimal outputs, being behavioral patterns, directly lead to actions which in turn bring about changes, indifferent if these are tiny ones or rather spectacular. Each and every action affects the social environment, thus cultural

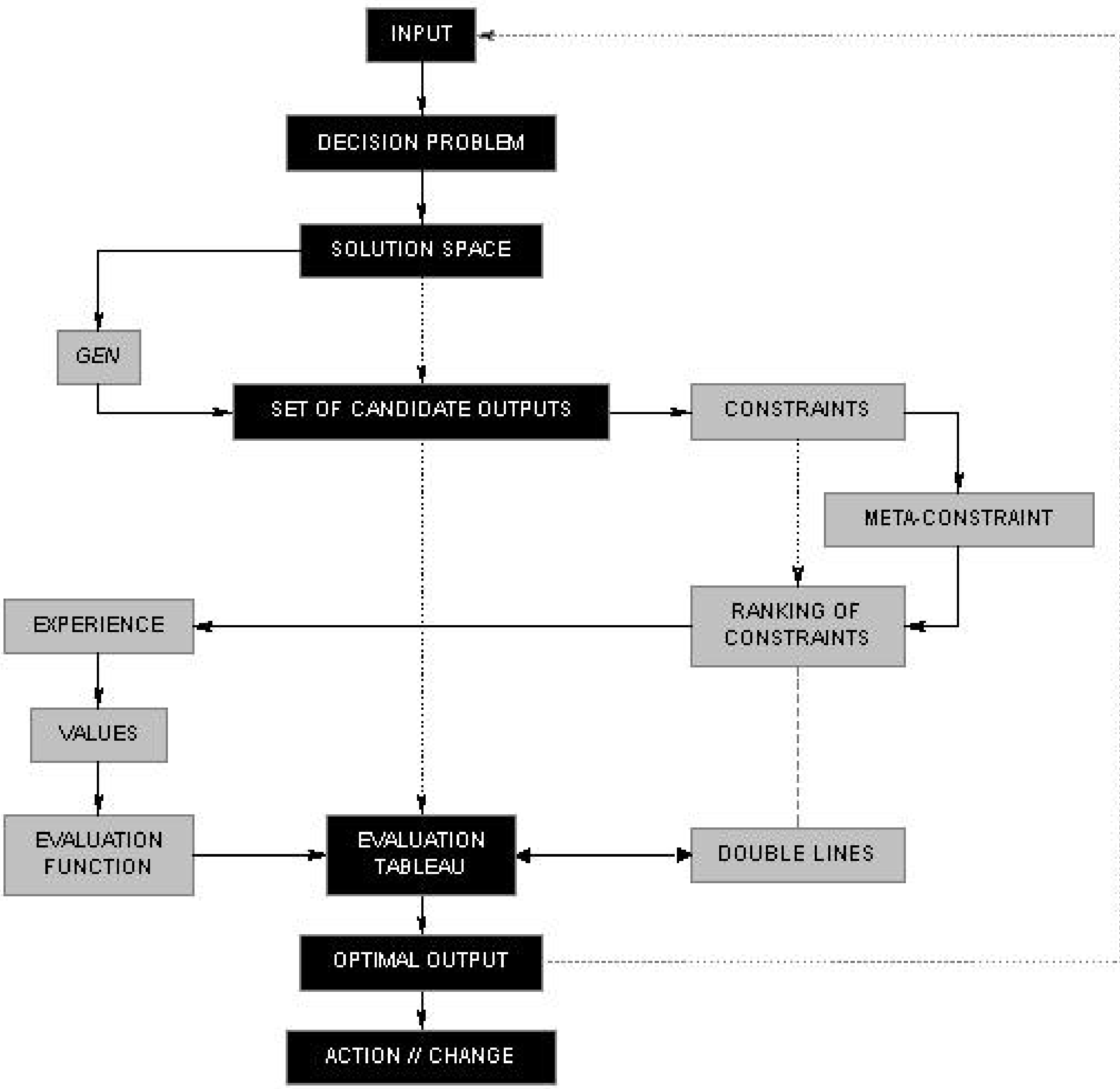

Figure 4.4: **The FR-model - Parts and process.** Flow chart depicting the procedural steps from the initial input to final optimal outputs, including a feedback loop option.

change is shown to be the resultant of actions characterized literally or hypothetically as optimal ones.[6]

Although the direct linkage from optimal outputs to action // change is the default endpoint of the whole procedure, the model also provides a feedback loop option, denoted in the diagram as a grey dotted arrow-line connecting optimal outputs with the input element. This option allows for optimal outputs to be reprocessed as new inputs in cases that outputs, being themselves a change of the DM-subject's preferences, are part of a situational setting that triggers a new instance of the model.[7] The feedback loop, therefore, provides both the field for quite interesting multi-level instantiations of the FR-model and a stimulating hint for philosophical investigations regarding the iterative character and the continuity of cultural change. Yet, in practical terms its consequences for the procedure described in the flow-chart are of minor importance, the reason being that new instances of the model, regardless of the nature of the input, follow the same step-by-step process in order to determine optimal outputs.

4.2 Elements of the FR-model

4.2.1 The Decision-Making Subject

All actions in the model are taken by the decision-making subject. The DM-subject acts either objectively or subjectively, depending on the particular task

[6]The macro level of this argument is rather obvious: there should be no doubt that decisions characterized optimal according to the described process, which concern large-scale plans and activities in terms of time or the population affected, bring about severe changes in the social setting. Such large-scale decisions include legislation, political and economic decisions in governmental level and much more of the kind. Yet, what is less clear is the micro level of the argument. In order to clarify the case one has to appeal to the accumulative effect micro-scale decisions may have. Thus a farmer's decision to cultivate, say, tomatoes instead of anything else, may have a negligible impact in the total agricultural production of a large geographical area; still, no matter how small the impact, the farmer's decision resulted in a change in the agricultural production of the area, which now contains a slightly increased tomato portion (instead of anything else). In this way, each and every optimal behavior may be considered to play a role in the bringing about of changes, in the very same sense that voting determines political change. The accumulative effect a number of similar small-scale activities and plans may have sharpens the case and explains why micro-level decisions should be regarded as parts of social, and in the most wide sense of the term, cultural change.

[7]In another similar option, optimal outputs of previous instances of the model do not appear directly as new inputs, but are generated as members of the set of candidate outputs, in multi-level processes. This variation of the feedback loop is clarified in example Case 1: leapfrog Economy, below 5.1, in which some candidate outputs are supposed to be the optimal outputs of previous instances of the model, all of which concern the same problem addressed in multiple levels.

undertaken in each step of the process. The output is externalized to the environment via the optimal output action performed by the DM-subject. One should think of the DM-subject as a human being. Collective subjects, such as a Parliament, are part of the DM-subject definition, but in order for the model to deal with such cases certain modifications are required concerning the following topics:

- The relation between the atomic characteristics of the members which compose the collective body and the characteristics of the collective subject.
- Issues to be resolved in terms of negotiations between the members of the collective body and in particular the ranking of constraints.

Though it is conceivable to think of non-human or even completely abstract entities as DM-subjects, the proposed model does not follow such a path. One might think transcendentally of entities like language, nature or evolution as DM-subjects which actually run instances of the model, thus explaining changes occurring in our environment, but this kind of reasoning presupposes *a priori* assumptions about the existential conditions of such entities and could rather easily end up in just anthropomorphic variations of the original concept.
Conclusively, the decision-making subject for the purposes of the FR-model is primarily a human being, or in special cases a collective body composed by any number of human beings.

4.2.2 Input

Inputs to the model appear as changes in the environment of the DM-subject, which usually take the form of *needs* or *interests*. The environment of the subject includes all information perceivable directly by the subject or via media extensions.

It is important to point out that optimal outputs from previous instances of the FR-model may be new inputs for subsequent instances, regardless of the subject running the previous instance. That is, the optimal output which serves as an input may be the result of the decision-making process undertaken by the same or some other subject. In the former case we have a change in the state of mind or the preferences of the subject. Therefore the FR-model aims to describe change as a dynamic process where optimal outputs or changes in the environment trigger new instances of the model, which in turn result in new changes via the actions undertaken by the subjects. An optimal output is always a form of action, even in the case of a "decision-loop" where the action performed is a new running of the model triggered by the change in the subject preferences. Needless to add that spatiotemporal changes, such as "new day", may very well serve as inputs to the model, especially in cases of routine activities, such as everyday actions or the annual sowing period. Each input comes with a detailed situational setting, defined in space and time and a time-span for response action. This setting is known to the subject for it simply occurs in the subject's informational environment. Therefore the subject is confronted with a change described in terms of particular situational characteristics which takes the form of a decision-problem.

4.2.3 Decision Problem

A decision-problem is the direct impact of an input. Actually it is the reduction of the input to a polar (yes - no) question concerning response to the input, which is formulated as:

Respond to the input: YES / NO;
if YES, determine optimal action;
else quit.

In this way every change // input is transformed into a decision-problem. All behaviors related to the input constitute the solution space for the problem under discussion including no-action (to be identified with no-change, but not with the quit response to the polar question) which is always part of the set of candidate outputs accounting for the ability of the model to deal with no-change situations, i.e. stability.

4.2.4 Solution Space

The solution space is an abstract construction which includes all possible solutions for a particular decision-problem. A semi-formal definition of the solution space would describe the contents of this set as "all actions related to the situational setting" with reference to some hypothetical relevance function.

According to that description the solution space includes both true and false solutions, as well as fallacious and unimaginable ones. Mere absurdities, magical behaviors (e.g. say mystic words), along with viable and true solutions are alike part of the solution space in a direct analogy with linguistic OT which accounts equally for wrong and right candidates, the latter to be thought as the optimal ones according to the theory. The existential status of the members of the solution space set can be formalized as follows: "Members of the solution space set do not exist, unless instantiated by the *GEN*".

In few words, the solution space is supposed to be a huge set of behaviors related to the problem, which is drastically diminished by the *GEN* to the realistic, much smaller set of candidate outputs.

4.2.5 The Generator (*GEN*)

The fact that OT does not provide a detailed theoretic description of the *GEN*, but rather presupposes such a theory for this crucial element of the model, as it is convincingly argued in [Blut1], increases the difficulties for the analogy between OT and the FR-model. In the case of practical issues, like the ones OT practitioners deal with usually, this lack of a theory about *GEN* is of minor importance. Unlike these cases, the FR-model has to provide, if not a theory, at least a descriptive definition of the *GEN*.

The *GEN* in the FR-model plays exactly the same role as in linguistic OT: it generates the set of candidate outputs, members of which will turn out through the evaluation process to be the optimal ones. The *GEN* is supposed to reside in the DM-subject and is determined individually for each subject by the I.B.I. factor (imagination - background - information).

Analytically: every human subject capable of undertaking decision-making tasks has certain mental abilities (collectively baptized imagination), which allow her to combine input information and imagine new combinations of situational elements with respect to a particular problem; furthermore, she has a unique history, which includes all past experiences and education (collectively baptized background); and finally she has access to perceptual or mediated information available to her environment (collectively baptized information). Therefore every subject is equipped with a unique *GEN* mechanism which functions in full accordance with the subject's I.B.I. factor. The unique individual *GEN* generates the set of candidate outputs by "downloading" all accessible elements from the solution space. Accessibility is of course determined by the I.B.I. factor. That is, if the subject lacks information or the appropriate background to see/access a solution that is included in the solution space, the *GEN* will be unable to generate that particular solution. In the same way the unimaginable members of the solution space set, as well as a great deal of absurd solutions are sorted out by the *GEN* as a result of the I.B.I. factor.[8]

[8] A **NB** is required in this point in order to make absolutely clear that the *GEN* does not select in any way candidates; it only generates them, according to the I.B.I. factor. As long as a possible solution is within the bounds of the subject's I.B.I., the *GEN* will unavoidably add it to the set of candidate outputs. This not being the case the model should provide a pre-selection function in quite an early stage of the process in addition to the OT-like function and assign a heavy double duty to the *GEN*. The premature adaptation of the *GEN* in the FR-model made it quite preferable to disregard the option of a pre-selection function and follow the standard OT scheme.

4.2.6 Set of Candidate Outputs

The set of candidate outputs is made up by all the "tangible", realistic solutions the *GEN* has generated from the solution space for a particular decision problem. These may be neither efficient, nor true. Noise, a notion conceptually borrowed from [Sh&We] and defined as the set of all factors that are capable of distorting the function of *GEN*, could have distorted the generative process and, consequently, one or more of the solutions which appear in the set of candidate outputs would turn out to be inadequate.
The set of candidates is the starting point for the evaluation process. The FR-model evaluates all members of the set of candidate outputs and returns the optimal ones. In terms of the evaluation function the set of candidate outputs is the domain of the function. For each argument in this domain the evaluation function will return a value in the range $\{0, 1\}$.[9] Thus for objects x which have the property Cnd(x) of being candidate outputs, the evaluation function is defined as follows:

$$EvalF(x): \; \{x|\, Cnd(x)\} \longrightarrow \{0,\, 1\}$$

The semantic interpretation for the members of the range has as follows: a value of 0 is to be identified with a Do Not Employ directive for the action described by the argument that receives this value (i.e. the member of the set of candidate outputs that receives a value of 0 is not optimal). Inversely, a value of 1 is to be identified with an Employ directive for the action described by the argument which receives this value (i.e. the member of the set of candidate outputs that receives a value of 1 is optimal). In addition, this definition of the evaluation function accounts for the ability of the FR-model to provide more than one optimal outputs, as it is also the case in linguistic OT.

4.2.7 Constraints

The concept of constraints is embodied in the FR model with a certain modification: whereas in linguistic OT constraints may only be violated, receiving, so to speak, a negative value, the FR model allows for both negative and positive values with respect to constraints, reflecting the idea that a particular candidate output may not violate, but conversely satisfy a constraint. As long as constraints in the model serve as evaluating criteria, positive values account for candidate-constraint

[9] Alternative lexical expressions for the range of the evaluation function are in terms of evaluation the expression $\{non-optimal,\, optimal\}$, or in operational terms the expression $\{do\ not\ employ,\ employ\}$

combinations which satisfy the respective criterion to the degree denoted by the value.

But where do constraints come from? In standard OT a global set of constraints is assumed. With respect to that global set, different rankings of the constraints give rise to different grammars to be found in the various languages. The FR-model follows a similar approach. Due to the fact that cultural change involves various different and complex phenomena, a flexible construction for the set of constraints is required in order for the model to account for these phenomena. The flexibility is achieved if we appeal to the particular features of each problem, which are included in the detailed situational setting that comes with the input.

There are two major sources out of which the DM-subject compiles the set of constraints for each input problem: the set of global constraints and the features of the particular situational setting.

In accordance with standard linguistic OT, the FR-model also assumes a global set of constraints which includes all constraints ever enforced. In turn, the members of this set are classified in broad common-sense categories, the most prominent being social-constraints, natural-constraints, moral-constraints and economic-constraints. This is a top-down construction, so one may easily imagine further subcategories within each main category, such as, for example, the subcategory law-constraints within the social-constraints. The DM-subject is aware of this global set of constraints. Of course she may not know all particular constraints and such a knowledge would be of no use to her since the particular features of the problem she is dealing with are the ones that determine the specific form of the constraints she is going to use. But she does know the existence of such a set and to a certain extend of the broad constraint categories which compose it. The way DM-subjects come to know the existence of the global set of constraints is by training.[10] Whenever a child attempts to behave in a way that breaks the law it is confronted with some formulation of the law-constraints which appears in the form of recommendations from adults in its environment. In the same way, whenever a child's desire for some expensive good yields an answer of the type "we do not have enough money for that", the child is confronted with some formulation of the economic-constraints. The important thing is that through training

[10]The parallelism between rules and constraints may be strengthened, at least in a Wittgensteinian philosophical framework, once the argument about constraint-learning by training is accepted. As in the case of rules one learns to follow them by training, in an analogous manner, if the parallelism holds, one becomes aware of constraints by training. Cf: "What is the criterion for the way the formula is meant? It is, for example, the kind of way we always use it, the way we are taught to use it." [Wittg, §190].

the subject has become aware of the fact that her actions and behaviors are confronted with members of the global set of constraints.[11] The second component that leads the DM-subject to determine a specific set of constraints for the particular input problem she is dealing with, are the features of the problem which come along the situational setting in the input. For each relevant feature in the setting a corresponding constraint may be employed.
Therefore the overall scheme is that the DM-subject determines the problem-specific constraints by modifying members of the global set of constraints according to the specific features in the situational setting of the input problem.

One last important note about the issue of determining the constraints: the subject is assumed to act objectively (to the best of her abilities) in the attempt to determine the constraints. First of all, both the Global Set of constraints and the situational setting are external to the subject, i.e. not subjectively defined. Second and equally important, a biased selection of constraints could only be interpreted as an attempt of the subject to yield the results she likes best; being the explanation-seeking theorist, or the decision-reaching individual, a subject that has pre-decide what the best result to her interests would be is just wasting her time by running the model; for such a subject already knows what the model can tell! The unbiased selection of constraints is the only option available, i.e. in this part of the model the DM-subject is reasonably assumed to act objectively.

4.2.8 The Meta-Constraint

The concept of the meta-constraint signifies a departure of the FR-model from standard OT. The meta-constraint is the way the FR-model attempts to capture the meta-concerns the subject may have for the constraints. Thus a meta-constraint is a constraint applied to each and every member of the set of constraints for a particular problem. Under the light of the fact that meta-concerns originate from atomic preferences, by capturing the subjects meta-concerns the meta-constraint accounts for one of the most difficult problems in decision-reaching processes: incorporating the subjects preferences.

Meta-concerns may be thought of as a more abstract way of describing what in everyday language would be second thoughts. These are the concerns about the

[11] The fact that natural-constraints are part of the global set, along with the fact that the very basic economic-constraints apply to even the most primitive economies, should discourage skepticists from claiming that not all subjects had the training that results in being aware of the global set of constraints.

concerns a certain problem yields; accordingly, the meta-constraint is a constraint on constraints. E.g. a problem regarding illegal actions yields a law-constraint; one's concerns about the duties of the law-abiding citizen -and not the concerns about the specific law-constraint- are to be considered the second level concerns. Meta-concerns are multi-dimensional. Economy, social habits and ethics are among the most prominent axes along which meta-concerns are developed. All these meta-concerns, as for the model, boil down to one thing: they shape the ranking of constraints by mirroring the individual preferences of the subject. Thus, by assigning a meta-value (the value of the meta-constraint) in every constraint the model aims to integrate in terms of quantification the multi-dimensional parameter of individual preferences.

A second aspect of the functional role of the meta-constraint regards the feedback loop option. In iterative instances of the model addressing the same or some closely related problem, the meta-constraint accounts for changes in the set of constraints: it allows for existing constraints to be re-weighted not only according to second level concerns, but also with reference to previous experiences.

One might argue that as long as meta-concerns are multi-dimensional in nature, the model should provide different meta-values for each of these dimensions. This is a quite reasonable objection, the answer to which is that the parameter the model is trying to capture in this particular step is the single-dimension individual preferences parameter and not every detail in the subjects meta-concerns. An attempt to capture meta-concerns in more than one dimensions would have both the following results:

1. A significant loss of generality by the elimination of the abstraction function which is an essential part of every model-building process. In this case a proportionally large construction would have to be added to the model in order to account for the multiple dimensions of the meta-constraint.
2. An equally significant increase in the number of computational calculations which is needed in order to reach a hierarchical ranking of constraints that would make the model less useful. Nevertheless, the benefits would be marginal, for either multi- or single-dimensional individual preferences would end up in a single ranking of constraints.

An almost different way to describe the concept of the meta-constraint is by making use of the notion of the universal constraint "cost vs. profit" or else "effort vs. happiness". It has to be noted, however, that this is only a difference in description and not a conceptual one. In both cases the meta-constraint functions identically: it determines the meta-values of the constraints, either as the resultant of various meta-concerns, or as a constraint-like reflection of the common-sense principle of minimum effort.

Re-describing the concept of meta-constraint in this way means that the meta-concerns of the subject are in accordance with the "effort vs. happiness" constraint. The meta-constraint implies that for every element in the set of constraints, effort should be minimized and utility maximized. Since not all constraints yield the same equilibrium between cost and profit with respect to particular actions, it is clear that different constraints should get different meta-values. Finally, the practical result of the meta-constraint is that the subject, expressing her individual preferences, assigns numeric meta-values to the constraints defining the relative importance of each one.

4.2.9 Ranking of Constraints

As discussed in the meta-constraint subsection above, in this part of the process the DM-subject acts subjectively, which is an essential presupposition as long as the model aims to explain behavior patterns taking into consideration individual preferences. This goal is achieved by ranking the constraints according to the relative importance they have for the DM-subject.

With reference to the meta-constraint the DM-subject subjectively assigns a meta-value in each constraint. This subroutine in the overall evaluation function is a Relative Weight function whose domain is the set of constraints and its range the interval [0,1] of $\mathbb{R}$. For every argument in the domain the Relative Weight function returns a numeric value in the [0,1] interval of $\mathbb{R}$. Thus for objects x which have the property Con(x) of being a constraint, the Relative Weights function is defined as follows:

$$RW(x):\ \{x|\,Con(x)\}\ \longrightarrow [0,\ 1]$$

The semantic interpretation of the returned values has as follows: a high value close to 1 means that the constraint which received this value is of relatively great importance for the DM-subject. Inversely, a low value close to 0 means that the constraint which received this value is of relatively minor importance for the DM-subject. The meta-values of the constraints are their respective Relative Weights expressed in numerals, for these are the values which signify the relative importance each constraint has for the DM-subject. The last step of this subroutine is to rank the constraints in hierarchical order starting off from the one with the higher Relative Weight in the front rank (first left position in the tableau) and ending with the one with the lowest Relative Weight in the back rank (last right position in the tableau).

Two more comments about the issue of ranking of constraints:

1. The definition of the Relative Weight function allows for one or more constraints to receive the same Relative Weight. This practically means that they would be placed in the same rank in the hierarchical order of constraints and semantically means that they are of equal importance for the DM-subject, which is a conceptually right option, though in terms of probability one unlikely to occur (values from an infinite set are assigned to the members of a finite and in most cases rather small set of constraints). In the extreme case that all constraints receive the same Relative Weight -that is, all are equally important-, the model will still function and return the optimal outputs; but this is a rather trivial case which actually denotes a subject whose atomic preferences exhibit minimal variation. Besides being highly unlikely to occur, the case of all equal meta-values does not constitute a problem for the functionality of the model.
2. If, in addition to the case described in comment 1 above, the value which all constraints receive is 0 the evaluation function will return an undefined division $\frac{0}{0}$. Thus the model will be unable to determine the optimal outputs and the process will be stopped. Indeed such a case favors the semantic interpretation of the evaluation process; a value of 0 for all constraints is to be interpreted as all of them being absolutely unimportant; as long as no constraint has any significance, constraints may be thought of as being switched to off position, for their functional role has been cancelled.

4.2.10 Experience

Previous experience enters the model in all cases where the input problem repeatedly occurs in different time periods. In such cases the evaluation function provides an appropriate measure (the Change vs. Current rate) and the corresponding calculation formula for incorporating previous experiences on the problem under discussion into the model.

Experience in the FR-model usually takes the form of numeric data regarding a measurable (numeric) constraint. The particular measure employed depends on the nature of the constraint. For example, in an input problem such as "new sowing period", where a MAX-PROD (maximize production) constraint is activated, last year's harvest, measured in whatever units (weight, volume, absolute number of products, etc.), incorporates previous experience into the model. The Change vs. Current rate of the evaluation function is formulated in such a way that cancels measuring units; therefore the DM-subject gets a pure numerical value which reflects previous experience.

As for novelty phenomena, i.e. input problems for which no previous experience exists a twofold solution is provided: either, as it would be the common-sense suggestion, the DM-subject uses data from the most similar problem, or employs the simplified mode of the evaluation function which takes into account only the anticipated value of the respective magnitude and not the Change vs. Current rate.

4.2.11 Values

There are three different input values in the evaluation process of the FR-model: the Relative Weights of constraints, the Change vs. Current Rate and the Degrees of Violation. The last two may alternate reciprocally or co-exist in the function according to the nature of the relevant constraint (numeric or non-numeric).

The Relative Weights are numeric values within the range [0,1] of $\mathbb{R}$. These are the values that the DM-subject has assigned to every constraint (that is, the meta-values are equivalent with the Relative Weights).

The Change vs. Current rate is a numeric value calculated for every candidate output constraint combination (i.e. for every $cell_{ij}$ in the tableau) and depends on both the data available for the measure under discussion (Current value) and the prediction for the value of the measure if the i candidate output action is employed (Change value). The formula for the calculation of the Change vs. Current Rate is:

$$\frac{Change\,(prediction)\;-\;Current\,(available\;stats)}{Current} \tag{4.1}$$

In this way:

- (a) a negative rate option is available
- (b) the units in which the particular magnitude is measured are cancelled.

The Degrees of Violation are values which are used to signify the effect each output action will yield with respect to every constraint (again these are values which appear in every $cell_{ij}$ of the tableau); Degrees of Violation are determined in terms of prediction and their range is the set:

$$\{--,\ -,\ \emptyset,\ +,\ ++\} \text{ or its numerical counterpart } \{-2,\ -1,\ 0,\ 1,\ 2\}$$

A negative Degree of Violation value in $cell_{ij}$ signifies a violation (-1) or a severe violation (-2) of constraint j by the action described in candidate output i; in analogous manner positive values signify limited (1) or absolute fulfillment (2) of the respective constraint. A value of 0 signifies no impact of the candidate output to the constraint.

4.2.12 Evaluation Function

The evaluation method used in the FR-model relies on both the standard constraint-violation technique employed in linguistic OT and quantitative methods widely used in statistics and economics. These two approaches are integrated in a single method which determines optimal outputs in a step-by-step procedure.

First of all, with respect to the evaluation function two types of constraints may be discriminated: the numeric ones, i.e. the ones which are easily measured in the units of some closely related measure and the non-numeric ones, i.e. the ones which are not easily measured in terms of quantification. An example for the former case would be a STUD-NUM (number of students) constraint in an input problem regarding effective methods of teaching where the absolute number of students is obviously an appropriate measure for the respective constraint. Analogously, the Gross National Product (GNP) is an appropriate measure for members of the subcategory investment-constraints, available space in square meters an appropriate measure for members of the subcategory location-constraints and so on. An example for the latter case would be an ENVIRONMENT (preserve the environment) constraint in an input problem regarding agricultural methods. Of course, one might propose a magnitude of penalties by international Non-Governmental Organizations for polluting the environment measured in monetary units or something of the kind. The DM-subject determines the type of the constraint taking into account the purposes of the particular investigation. In terms of the evaluation process the type of the constraint is not essential since the evaluation function integrates formulae for both types.

The step-by-step procedure starts off with the values of the cells. Every combination of candidate output i with constraint j (i.e. every cell $Cell_{ij}$ in the evaluation Tableau) receives a value as follows:

1a. For numeric constraints the formula is:

$$Cell\_Value_{ij} = \frac{RW_j \times CVC_{ij}}{\sum_{j \in \mathbb{N}}^{n} RW} \tag{4.2}$$

This reads: the value of the cell in the row of candidate output i and the column of constraint j is the product of the Relative Weight of constraint j times the CVC rate for $Cell_{ij}$, divided by the sum of Relative Weights. The CVC Rate is calculated by the formula (repeated from 4.2.11 above) :

$$\frac{Change\,(prediction) - Current\,(available\ stats)}{Current}$$

1b. If no current statistics are available, as would be the case in novelty phenomena for which no previous experience exists, instead of the CVC rate only the Change magnitude is used and the $Cell\_Value$ formula is simplified accordingly.

2. For non-numeric constraints the formula is:

$$Cell\_Value_{ij} = \frac{RW_j \times DV_{ij}}{\sum_{j \in \mathbb{N}}^{n} RW} \tag{4.3}$$

This is exactly the same formula as the one for numeric constraints, the only difference being that instead of the CVC rate, the Degrees of Violation measure is used. The Degrees of Violation are values which are used to signify the effect each output action will yield with respect to every constraint; thus Degrees of Violation are determined in terms of prediction. The range of the Degrees of Violation is the set (repeated from 4.2.11 above):

$$\{--,\ -,\ \emptyset,\ +,\ ++\} \text{ or its numerical counterpart } \{-2,\ -1,\ 0,\ 1,\ 2\}$$

In the first step of the procedure, cell values are calculated only for the cells that lie before the first of what is hereafter technically called a "Double Line". Double Lines function as evaluation hallmarks, i.e. steps in the evaluation procedure in which the function is executed for whatever values have been attributed to the candidates up to that certain point. Thus a Double Line is a check point in which weak candidates are disregarded (killed) in comparison with the top level candidate and only the ones which survive (survivors) may proceed to the next Double Line. The number and placement of the Double Lines is determined by the DM-subject with respect to the nature, the number and the Relative Weights of the constraints.

For each candidate output a partial numeric value is calculated, in the case of numeric constraints according to the formula:

$$pNVO_i \;=\; \sum_{j\in\mathbb{N}}^{k}\left(\frac{RW_j \;\times\; CVC_{ij}}{\sum_{j\in\mathbb{N}}^{n} RW}\right) \tag{4.4}$$

In the case of non-numeric constraints, the formula is modified accordingly:

$$pNVO_i \;=\; \sum_{j\in\mathbb{N}}^{k}\left(\frac{RW_j \;\times\; DV_{ij}}{\sum_{j\in\mathbb{N}}^{n} RW}\right)$$

This is the sum of the $Cell\_Values$ in the row of candidate output i up to constraint k, which is the last one before the Double Line. This process of calculations results in the set of partial numeric values (pNV):

$$\text{pNV} \;=\; \{pNVO_1,\; pNVO_2, \ldots\; pNVO_n\}$$

Candidate outputs compete with each other and the stronger ones survive. As long as cell values are calculated with respect to predictions, in both the cases of numeric and non-numeric constraints, an error rate is reasonably assumed, as a harmonization factor in order to reduce the distorting effect less accurate predictions may have. The error rate for each constraint takes into account the Relative Weight of the constraint. The formula for calculating the error rate of constraint j has as follows:

$$ER_j \;=\; \frac{RW_j}{2 \;\times\; \sum_{j\in\mathbb{N}}^{n} RW} \tag{4.5}$$

That is, the error rate for constraint j is the Relative Weight of constraint j over two times the sum of relative weights. Up to the first Double Line error rates have an accumulative effect which is reflected in the error rate calculated for the column of the Double Line. The assumption underlying the formula for the calculation of the Double Line error rate (DLE) is that the maximum of error rates to the left of the Double Line has the strongest impact in the degree of divergence partial numeric values may have. The maximum error rate is the maximum value in the set ER of the error rates of all constraints before the Double Line. Thus, the formula for the calculation of the Double Line error rate has as follows:

$$DLE = ER_{max} + [\sum_{j \in \mathbb{N}}^{n} (\frac{ER_j}{2}) - \frac{ER_{max}}{2}] \tag{4.6}$$

The Double Line error rate is used for the computation of confidence intervals for all the members of the set of partial numeric values. Therefore every $pNVO_i$ is more confidently represented by a pair of values ($pNVO_{iHigh}$, $pNVO_{iLow}$) which correspond to the higher and the lower limit of its confidence interval. The formulae for the higher and lower limits of partial numeric values are:

$$pNVO_{iHigh} = pNVO_i + DLE \tag{4.7}$$

$$pNVO_{iLow} = pNVO_i - DLE \tag{4.8}$$

The selection of survivors in Double Lines follows the sharp techniques of standard OT. The top level candidate, i.e. the one with the maximum $pNVO$, is used for the determination of the survival threshold, which is defined as being equal to the lower limit of the confidence interval of the top level candidate. The partial numeric values of all other candidates are compared with this survival threshold, and only the ones whose higher limit is equal to, or greater than the threshold survive. In formula:

$$\text{If } pNVO_{iHigh} \geq pNVO_{maxLow} \text{ retain candidate output i ;}$$
$$\text{Else Kill} \tag{4.9}$$

This reads: if the higher limit of the confidence interval of candidate output i is equal to, or greater than the lower limit of the confidence interval of the candidate with the maximum partial numeric value up to (this) Double Line, retain candidate output i. Else kill candidate output i (candidate is expelled from the rest of the evaluation process).

The same procedure is repeated in every consequent Double Line, only for the candidate outputs which survived from the previous Double Lines.

One important note here is that survivor candidates do not pass along with them their respective partial values. That is, in every new Double Line the procedure starts from scratch and previous performance of the survivors is not taken into consideration. Double Lines are points of evaluation in which all the constraints on the left of each Double Line up to the previous one (or to the front rank constraint in the case of Double Line 1) are grouped together, and candidates compete each time with respect to the particular group of constraints.[12]

The evaluation procedure is repeated as many times as the number of Double Lines. If there is only one survivor before the end of the Double Lines, the Double Line process may finish, for in all subsequent Double Lines the $pNVO_{iHigh}$ of survivor i obviously will be greater than the lower limit of its own confidence interval in the singleton of partial numeric values. Consequently, the survivor is directly transferred to the last step of the evaluation function (i.e. the select function).

In the last step, the set of final numeric values (fNV) contains the total sum of all the $Cell\_Values$ in the respective row of each survivor from the last Double Line onwards; survivors in this step are evaluated according to a select function which is the last part of the evaluation function. The select function's domain is the set of final numeric values (fNV) and its range the set {0, 1} where a value of 0 is interpreted as non-optimal and a value of 1 is interpreted as optimal. Thus for objects x which have the property *Sur*(x) of being final survivors, the select function is defined as follows:

$$SelF(x): \ \{x|\, Sur(x)\} \ \longrightarrow \{0,\, 1\}$$

[12] Although the issue of passing values may seem at first sight simply a technical one, this is not the case. The answer to the question whether candidate outputs should retain their respective values after the evaluation process in each of the Double Lines, or not, is a critical one, and there has been a lot of argumentation about this issue during the construction period of the model. The argument in favor of candidates to retain their values was grounded on the fact that constraints on the left of the Double Lines are by definition relatively more significant than the ones after the Double Lines; hence, if candidates abolish their values, higher level acquirements would be endangered of being cancelled by poor performances in lower levels. Under this rationale passing values for survivors are thought to be essential exactly because these values reflect the performance of candidates when confronted with a group of higher ranked constraints. On the other hand, and that was indeed the argument that led to the adoption of the non-passing alternative, the whole concept of Double Lines would be trivialized if the values acquired by the candidates in the very beginning of the process travel all the way to the end of the Tableau, only making intermediate breaks in Double Lines. In addition, the fact that Double Lines extend and make more acute the original OT evaluation technique, favored the non-passing values option, which is the one that was finally incorporated in the FR-model.

The formula according to which the select function determines the optimal outputs is:

$$\text{If } fNVO_i \text{ is max } \in \text{ fNV, then } O_i = 1\,;$$
$$\text{Else } O_i = 0 \tag{4.10}$$

Conclusively, the evaluation function under the multi-step Double Line method determines for each and every member of the set of candidate outputs if it is optimal or not.[13] The possibility that the set of final numeric values (fNV) may have more than one element with the maximum value accounts for the fact that the FR-model licenses more than one optimal outputs.

4.2.13 Double Lines

The Double Lines concept is a modification of the standard evaluation method used in linguistic OT and divides the overall evaluation function into fractions. Therefore, Double Lines:

- Reduce the computational burden.
- Make the procedure more effective by killing inadequate candidates in early stages.

In terms of the tableau a Double Line is a column between the columns of constraints in which killed candidates are marked with an "x" sign and are expelled from the rest of the process. In comparison, standard OT's Eval may be considered to function along Double Lines in every step of the process, i.e. each column of the evaluation tableau in OT corresponds to a Double Line.

Methodologically a Double Line is a way of grouping together constraints and evaluate candidates with respect to every particular constraint group. Double Lines are placed in order of execution from left to right, corresponding to groups of constraints in order of significance. There is no other rule regarding Double Lines. There may be as many as the DM-subject wants or even none, and be placed anywhere in the tableau. The placement of Double Lines signifies steps of evaluation, i.e. all candidates are evaluated with respect to the constraints belonging to the group which lies before (to the left) of the Double Line and the survivors pass on to the next step. The evaluation function in every Double Line relies on the partial sum of the cell values of each candidate output, the error rate

[13] Obviously killed candidates are considered non-optimal. Trivially one may assume a kill function which maps members of the set of killed candidates to the set $\{0\}$.

and a simple, yet quite sharp, formula for the discrimination of candidates to be killed and survivors.

4.2.14 Evaluation Tableau

The evaluation tableau is a characteristic feature of linguistic OT. Actually the tableau is a diagrammatic way of displaying all the data related to the evaluation process. The tableau contains the members of the set of candidate outputs, all the constrains in the ranking order from left to right and the values for the combination of each candidate output with all the constraints. In the FR-model's variation of the evaluation tableau, Double Lines appear as new columns between groups of constraints; in these new columns the "x" marks, denoting killed candidates, are displayed.

In all cases the tableau allows the reader to determine "at a glance" the optimal outputs by just looking at the values in each cell. In standard OT optimal Outputs are signed with a hand that points to the winning candidates. For all the above reasons the tableau is thought of by OT practitioners as a kind of registered trademark for the theory and every new development in the respective field incorporates displaying tableaux to some extend. For exactly the same reasons, the FR-model employs the evaluation tableau as a means of both resembling its relation with linguistic OT and providing a pictorial summary of the whole evaluation process.

4.2.15 Optimal Output

The evaluation function returns for each element in the set of output candidates a value of 0 (Do Not Employ) or 1 (Employ). Candidates receiving a value of 1 are considered optimal and the actions they describe are appropriate, optimal responses to the input change. As in standard linguistic OT we may have multiple optimal outputs. From a theoretic perspective that does not constitute any kind of problem, for in theory you may have multiple optimal solutions to a decision-problem all of which get an equal probability value according to the number of optimal outputs. That is, for n optimal outputs each has a probability $\frac{1}{n}$ to be implemented as actual behavior.

In practical cases, where the FR-model is used operationally as a decision-reaching tool and one is confronted with mutually exclusive multiple optimal outputs (e.g. one may not invest 50% and 70% of her available budget simultaneously for the same economic goal), further constraints should be added. In most cases even one more constraint should resolve the issue, let alone more than one or consequent additions of constraints, though in theory the procedure of getting a single optimal output may never terminate. Of course this last case is highly improbable and would practically mean that one is dealing with identical candidate outputs.

4.2.16 Action // Change

A behavioral pattern or action is the final output of the model. The action employed is the action described in the output behavior which was evaluated as optimal by the evaluation process and is the response to the question posed by the decision-problem. In this framework change is to be explained as the product of a decision-making process which leads to optimal action. Furthermore, due to the fact that cultural change is for the most part the result of human actions, either in micro- or macro-scale, change is shown to be essentially a matter of competing constraints which determine optimal behaviors, in the exact same sense that constraints function in linguistic Optimality Theory.

Finally, the fact that optimal outputs may in turn lead to actions which involve new instances of the FR-model attaches a dynamic perspective to the overall process and explains why there is no actual starting point for cultural change. Instead, the initial cultural Big Bang should be traced back in time in some kind of an Archeology of Constraints, to use Foucault's favorite term for historical investigations, all of which have determined the decisions and actions of humans in the past and eventually changed human societies.

Chapter 5

Shifting, Marking and Writing E-Mails

5.1 Case 1: Leapfrog Economy

5.1.1 Case 1: Situational Setting

The term leapfrog is used sometimes in order to describe developmental practices in which certain stages are omitted in favor of a higher degree of efficiency, or there is a direct shift from one practice to another, for the same purpose. Therefore, a leapfrog program is one that "leaps-like-a-frog" -as in the leapfrog game in which players leap over each other's back- between established and alternative solutions for a particular problem, or leaps over certain phases in a linear procedure in order to achieve higher level results in a shorter period of time. Regarding macroeconomics it has been suggested that underdeveloped agricultural economies could take a leapfrog program over industrial phases as to keep pace with post-industrial economic globalization.

Example case 1 concerns a decision-problem in such an economy. One may imagine an underdeveloped economy somewhere in the so-called Third World which follows a classic industrial development program. An overseas-educated citizen of the country returns home and proposes a leapfrog developmental program for the country's economy (input). The DM-subject could be the Parliament or some sort of economic council, though for simplicity an individual subject, like the Minister of Economics or some other policy-maker, may be assumed.

5.1.2 Case 1: Analysis

From all possible actions included in the solution space the *GEN* under the influence of the I.B.I. factor has generated the following set of candidate outputs:

1. Maximum investments in info-technologies.
2. Info-tech investments only in selected sectors.
3. Split budget for investments in both industrial and information technologies.
4. Pilot program in limited geographical areas.
5. No investments in info-tech (standard industrial program).

It is worth noting at this point that the specific formulation of candidate outputs 2, 3 and 4 is the result of the feedback loop option of the model. That is, candidate output 4, for example, includes all characteristics of the respective proposal, such as duration of the pilot program, geographic location, etc. Thus candidate output 4 should be thought of as the optimal output of a previous instance of the model, dealing with the same input problem in lower-level as part of a multi-level process. The previous instance of the model, in this particular example, would embrace competing candidate outputs of the same form as the final optimal output which entered the new instance as candidate 4; that is, competing candidates of the type "pilot program in area A, of duration B, etc." versus "pilot program in area C, of duration D, etc." among others of the same type. The same holds, *mutatis mutandis*, for candidate outputs 2 and 3, which should also be thought of as optimal outputs from respective previous instances of the model, thus exploiting the feedback loop option.[1]

The members of the set of constraints, their interpretation, type, measurement method and units, and respective Relative Weights (meta-values assigned by the DM-subject) in hierarchical order (front rank to back rank) are the following:

1. Name: ECONOMY (ECON)
   Interpretation: Maximize economic growth
   Type: Numeric
   Measurement: Gross National Product in monetary units
   Relative Weight: 0.8

[1] In addition to footnote 4.7 above, it should be noted that in its pure form the feedback loop refers to cases in which optimal outputs trigger new instances of the model and appear as direct inputs. The variation presented in this example (optimal outputs as members of a new set of candidates) occurs in multi-level decision-problem processing.

2. Name: EMPLOYMENT (EMPL)
   Interpretation: Maximize employment
   Type: Numeric
   Measurement: Percentage of employed population
   Relative Weight: 0.7

3. Name: ENVIRONMENT (ENVI)
   Interpretation: Preserve both urban and natural environment
   Type: Non-Numeric
   Measurement: Degrees of Violation
   Relative Weight: 0.5

4. Name: SOCIAL-BENEFITS (S-BEN)
   Interpretation: Consider indirect social benefits
   Type: Non-Numeric
   Measurement: Degrees of Violation
   Relative Weight: 0.3

This example encounters one Double Line, positioned between the second and the third constraint. By this positioning of the Double Line constraints are grouped according to type and significance. So the purely economic constraints of type numeric as a group fall to the left of Double Line, whereas all the rest fall to the right.

Following the FR-model's procedural line, in the first step cell values are calculated only for the columns to the left of the Double Line.[2]. The interaction of constraints with the anticipated effects each candidate output may have to the respective measures gives rise to the following predictions:[3]

---

[2] This is due to an underlying "minimize effort" assumption of the model. As long as Double Lines are evaluation steps and killed candidates are expelled from the rest of the process, cell values for these candidates to the right of the Double Line are apparently superfluous.

[3] All predictions for the example cases are obviously oversimplified and solely appear for demonstration purposes. They are based on prevalent stereotypes on their relevant areas, of the type "info-technologies increase unemployment, but they are environment-friendly" and the like, many of which may be false, to say the least. Still, misleading stereotypes are completely irrelevant to the purposes of the demonstration, for the model does not evaluate predictions *per se*, but candidate outputs (taking into account predictions), thus the functionality of the model which is demonstrated in the example implementations is not affected by the quality of predictions, though, of course, the results may be far from realistic.

Outputs	ECON	EMPL
Max Investment	1500	0.85
Selected Sectors	1400	0.90
Split Budget	1300	0.90
Pilot Program	1200	0.91
No Info-Tech	1100	0.94

Case 1: Predictions for group 1 constraints.

Values for the cells under numeric type constraints are calculated according to formula 4.2. The CVC rate part of the numerator's expression is given by formula 4.1 and (the sum of the Relative Weights) $\sum_{j=1}^{4} RW = 2.3$. The Current value of Gross National Product is assumed to be 1000 monetary units and the Current employment rate 92% of the population. Thus:

$$Cell_{11} = \frac{0.8 \times \frac{1500-1000}{1000}}{2.3} \simeq \boxed{0.17} \quad || \quad Cell_{12} = \frac{0.7 \times \frac{0.85-0.92}{0.92}}{2.3} \simeq \boxed{-0.023}$$

$$Cell_{21} = \frac{0.8 \times \frac{1400-1000}{1000}}{2.3} \simeq \boxed{0.14} \quad || \quad Cell_{22} = \frac{0.7 \times \frac{0.90-0.92}{0.92}}{2.3} \simeq \boxed{-0.006}$$

$$Cell_{31} = \frac{0.8 \times \frac{1300-1000}{1000}}{2.3} \simeq \boxed{0.10} \quad || \quad Cell_{32} = \frac{0.7 \times \frac{0.90-0.92}{0.92}}{2.3} \simeq \boxed{-0.006}$$

$$Cell_{41} = \frac{0.8 \times \frac{1200-1000}{1000}}{2.3} \simeq \boxed{0.07} \quad || \quad Cell_{42} = \frac{0.7 \times \frac{0.91-0.92}{0.92}}{2.3} \simeq \boxed{-0.003}$$

$$Cell_{51} = \frac{0.8 \times \frac{1100-1000}{1000}}{2.3} \simeq \boxed{0.03} \quad || \quad Cell_{52} = \frac{0.7 \times \frac{0.94-0.92}{0.92}}{2.3} \simeq \boxed{0.006}$$

Given the $Cell\_Values$, formula 4.4 returns the partial numeric values for each candidate output i ($pNVO_i$) up to the Double Line by adding the $Cell\_Values$ in the respective row. In order to compute the confidence interval for each candidate the Double Line error rate is needed. The error rate for each constraint is calculated according to formula 4.5. Thus:

$$ER_1 = \frac{RW_1}{2 \times \sum_{j=1}^{4} RW} = \frac{0.8}{2 \times 2.3} \simeq \boxed{0.17}$$

$$ER_2 = \frac{RW_2}{2 \times \sum_{j=1}^{4} RW} = \frac{0.7}{2 \times 2.3} \simeq \boxed{0.15}$$

Therefore the Double Line error rate may be computed according to formula 4.6:

$$DLE = ER_{max} + [\sum_{j=1}^{2} (\frac{ER_j}{2}) - \frac{ER_{max}}{2}] = 0.17 + (\frac{0.32}{2} - \frac{0.17}{2}) \simeq \boxed{0.25}$$

In turn, according to formulae 4.7 and 4.8 the confidence intervals for each candidate output are computed. The pairs of higher and lower limits of the confidence interval for each candidate output have as follows:

$$\sum_{j=1}^{2} Cell_{1j} \pm DLE = 0.150 \pm 25\% \Rightarrow \begin{cases} pNVO_{1High} \simeq \boxed{0.188} \\ pNVO_{1Low} \simeq \boxed{\underline{0.113}} \end{cases}$$

$$\sum_{j=1}^{2} Cell_{2j} \pm DLE = 0.134 \pm 25\% \Rightarrow \begin{cases} pNVO_{2High} \simeq \boxed{0.167} \\ pNVO_{2Low} \simeq \boxed{0.101} \end{cases}$$

$$\sum_{j=1}^{2} Cell_{3j} \pm DLE = 0.094 \pm 25\% \Rightarrow \begin{cases} pNVO_{3High} \simeq \boxed{0.117} \\ pNVO_{3Low} \simeq \boxed{0.070} \end{cases}$$

$$\sum_{j=1}^{2} Cell_{4j} \pm DLE = 0.067 \pm 25\% \Rightarrow \begin{cases} pNVO_{4High} \simeq \boxed{0.083} \\ pNVO_{4Low} \simeq \boxed{0.050} \end{cases}$$

$$\sum_{j=1}^{2} Cell_{5j} \pm DLE = 0.036 \pm 25\% \Rightarrow \begin{cases} pNVO_{5High} \simeq \boxed{0.045} \\ pNVO_{5Low} \simeq \boxed{0.029} \end{cases}$$

The survival threshold, defined as the lower limit of the maximum $pNVO$, is:

$$pNVO_{maxLow} = \boxed{0.113}$$

According to formula 4.9 the higher limits of all other candidates are compared with the survival threshold and the survivors are the ones whose higher limit is equal to, or greater than, the value of the threshold. Thus survivors from the Double Line are **candidate 1 (maximum), candidate 2** and **candidate 3**. All other candidates are killed (expelled from the rest of the process).

The same process is repeated in order to compute the set of final numeric values for the survivors.

The interaction of constraints with the anticipated effects each candidate output may have to the respective measures gives rise to the following predictions:

Outputs	ENVI	S-BEN
Max Investment	+ +	+
Selected Sectors	+	+
Split Budget	+	+

Case 1: Predictions for group 2 constraints.

Values for the cells under non-numeric type constraints are calculated according to formula 4.3. The DV part of the numerator's expression is taken directly from the respective predictions and, again, (the sum of the Relative Weights) $\sum_{j=1}^{4} RW = 2.3$. Thus:

$$Cell_{13} = \frac{0.5 \times 2}{2.3} \simeq \boxed{0.43} \;||\; Cell_{14} = \frac{0.3 \times 1}{2.3} \simeq \boxed{0.13}$$

$$Cell_{23} = \frac{0.5 \times 1}{2.3} \simeq \boxed{0.22} \;||\; Cell_{24} = \frac{0.3 \times 1}{2.3} \simeq \boxed{0.13}$$

$$Cell_{33} = \frac{0.5 \times 1}{2.3} \simeq \boxed{0.22} \;||\; Cell_{34} = \frac{0.3 \times 1}{2.3} \simeq \boxed{0.13}$$

The set of final numeric values contains the sum of cell values to the right of the Double Line for each survivor candidate. Thus:

$$\sum_{j\in\{3,4\}}^{4} Cell_{1j} = \boxed{\underline{0.56}} \;||\; \sum_{j\in\{3,4\}}^{4} Cell_{2j} = \boxed{0.35} \;||\; \sum_{j\in\{3,4\}}^{4} Cell_{3j} = \boxed{0.35}$$

Finally, according to the select function, optimal outputs are determined. Thus:

$$SelF(fNVO_i) = \begin{cases} 1 & \text{if max} \in \text{fNV} \\ 0 & \text{otherwise.} \end{cases}$$

$$SelF(fNVO_1) = \boxed{1} \; || \; SelF(fNVO_2) = 0 \; || \; SelF(fNVO_3) = 0$$

The semantic interpretation of the returned values is that **candidate output 1, maximum investments in info-technologies, is optimal** (else, "employ candidate output 1"). All the above are summarized in OT's trademark, the evaluation tableau:

Constraints → **↓ Outputs**	ECON	EMPL	DOUBLE LINE	ENVI	S-BEN	**fNVO**
☞ Max Investment	0.17	-0.023	0.188 High <u>0.113</u> Low	0.43	0.13	0.56
Selected Sectors	0.14	-0.006	0.167 High 0.101 Low	0.22	0.13	0.35
Split Budget	0.10	-0.006	0.117 High 0.070 Low	0.22	0.13	0.35
Pilot Program	0.07	-0.003	0.083 High 0.050 Low ✘			
No Info-Tech	0.03	0.006	0.045 High 0.029 Low ✘			

5.2 Case 2: The Effort of Marking Human-Objects

5.2.1 Case 2: Situational Setting

Case marking human objects requires two different types of effort: a materialistic, articulatory one, with respect to the material (sound) added, and a conceptual one, with respect to the decision as to whether to mark or not a human object.

> "It is common for languages with overt case marking of direct objects to mark some objects, but not others. Following Bossong (1985), I call this phenomenon DIFFERENTIAL OBJECT MARKING (DOM)."[4]

An OT account of this phenomenon is provided in details in [Aisse], in terms of harmonic alignment.[5] The particular scales which are aligned in the OT explanation of the phenomenon are Definiteness and Animacy. Along these dimensions the prominence of direct objects is assessed in order to account for the DOM model's fundamental assumption, according to which "the higher in prominence a direct object, the more likely it is to be overtly case marked".[6] One of the most interesting conclusions of the harmonic alignment explanation of DOM is the high degree of relative markedness for human objects, as shown in figure 5.1:

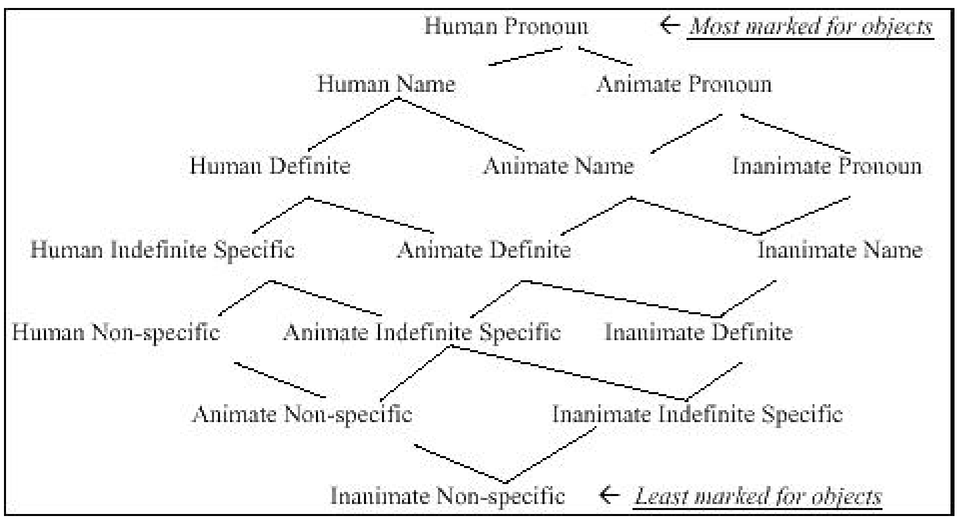

Figure 5.1: Relative markedness with respect to animacy and definiteness. Source: [Aisse, p.17]

The overall issue of DOM is resolved in the harmonic alignment framework in terms of equilibria between iconicity which favors case marking in order to maximize clarity and economy which penalizes case marking in order to minimize effort. In addition to this aspect of linguistic economic constraints a more radical,

[4] [Aisse, p.2]

[5] "The OT account of DOM requires, first of all, constraints which characterize the relative markedness of various associations of grammatical function with animacy and definiteness. (...) Harmonic alignment operates on pairs of scales, aligning each element on one with each element on the other, and it generates constraint sub-hierarchies which express the relative markedness of each such association." [Aisse, p.5]

[6] [Aisse, p.2]

evolutionary aspect of linguistic economy has been proposed by Haspelmath in [Haspe].

> "Loosely speaking, what is good from the point of view of the theory is good from the point of view of language users. Grammatical optimality and user optimality are largely parallel. The obvious way of accounting for this striking match between grammatical structures and speaker needs is the notion of **adaptation**. Grammatical structures are adapted to the needs of language users."[7]

The only assumption that needs to be made for the notion of user optimality to be integrated in an economy framework of equilibria between effort and gain is that language users respect the principle of minimum effort; that is, a user-optimal solution is one which achieves the highest level equilibrium between effort and efficiency. Under this reservation the phenomenon of case marking human objects is analyzed using the FR-model in a historical perspective along the axes of the articulatory, sound adding effort and the marking-decision effort.[8] In particular a historically precedented period is assumed, during which the articulatory effort is shown to be the determinative factor (mirrored in the positioning of the Double Line - the Double Line period), and a subsequent one during which the marking-decision effort shapes the results (the post-Double Line period).[9]

5.2.2 Case 2: Analysis

The Double Line period

From all possible actions included in the solution space the *GEN* under the influence of the (investigator's) I.B.I. factor has generated the following set of candidate outputs:

1. Never mark a human object.
2. Always mark a human object.

---

[7] [Haspe, p.5], emphasis in the original.

[8] As mentioned before, this is an example case of the theoretic perspective of the model, involving an explanation seeking investigator. It also illustrates the use of the Double Lines as evaluation steps, the presence or absence of which may be critical, especially in the explanatory mode. Though the implementations of the model serve merely demonstration purposes, the positioning of the Double Line in this case is *ipso facto* part of the explanation.

[9] An indicative attempt to explain this twofold account of human object marking suggests that the articulatory effort, being quite a matter of basic skills, is considered relatively primitive as opposed to the sophisticated nature of the conceptual effort needed in order for case marking decisions to be made.

3. Decide in every case whether to mark or not.

The members of the set of constraints, their interpretation, type, measurement method and units, and respective Relative Weights in hierarchical order are the following:

1. Name: CONFUSION (CONF)
   Interpretation: Avoid creating confusion[10]
   Type: Non-Numeric
   Measurement: Degrees of Violation
   Relative Weight: 0.8

2. Name: MATERIAL (MATL)
   Interpretation: Minimize articulatory effort
   Type: Non-Numeric
   Measurement: Degrees of Violation
   Relative Weight: 0.6

3. Name: DECISION (DECI)
   Interpretation: Minimize marking-decision effort
   Type: Non-Numeric
   Measurement: Degrees of Violation
   Relative Weight: 0.4

This part of the example encounters one Double Line, positioned between the second and the third constraint. Thus, only the most primitive and historically more powerful constraints fall to the left of the Double Line, whereas the constraint regarding the conceptual effort is the only one left to the right of the Double Line.

Following the FR-model's procedural line, in the first step cell values are calculated only for the columns to the left of the Double Line. The interaction of constraints with the anticipated effects each candidate output may have to the respective measures gives rise to the following predictions:

[10]As in all cases of non-numeric constraints, positive values of the Degree of Violation measure signify success and, inversely, negative values signify failure. In the case of the CONFUSION constraint, for example, positive DV values signify candidate outputs which do not create confusion (succeed in avoiding). Indeed, sometimes this interpretation may seem counter-intuitive due to the naming of the Degree of Violation measure which was chosen to reflect the original OT technique of evaluation - one that depends on the violation of constraints in the literal sense.

Outputs	CONF	MATL
Never Mark	$--$	$++$
Always Mark	$++$	$--$
Marking-Decision	$+$	$\emptyset$

Case 2, Double Line period: Predictions for group 1 constraints.

Values for the cells under non-numeric type constraints are calculated according to formula 4.3. The DV part of the numerator's expression is taken directly from the respective predictions and (the sum of the Relative Weights) $\sum_{j=1}^{3} RW = 1.8$. Thus:

$$Cell_{11} = \frac{0.8 \times (-2)}{1.8} \simeq \boxed{\text{-0.89}} \; || \; Cell_{12} = \frac{0.6 \times 2}{1.8} \simeq \boxed{0.67}$$

$$Cell_{21} = \frac{0.8 \times 2}{1.8} \simeq \boxed{0.89} \; || \; Cell_{22} = \frac{0.6 \times (-2)}{1.8} \simeq \boxed{\text{-0.67}}$$

$$Cell_{31} = \frac{0.8 \times 1}{1.8} \simeq \boxed{0.22} \; || \; Cell_{32} = \frac{0.6 \times 0}{1.8} = \boxed{0}$$

Given the $Cell\_Values$, formula 4.4 returns the partial numeric values for each candidate output i ($pNVO_i$) up to the Double Line by adding the $Cell\_Values$ in the respective row. In order to compute the confidence interval for each candidate the Double Line error rate is needed. The error rate for each constraint is calculated according to formula 4.5. Thus:

$$ER_1 = \frac{RW_1}{2 \times \sum_{j=1}^{3} RW} = \frac{0.8}{2 \times 1.8} \simeq \boxed{0.22}$$

$$ER_2 = \frac{RW_2}{2 \times \sum_{j=1}^{3} RW} = \frac{0.6}{2 \times 1.8} \simeq \boxed{0.17}$$

Therefore the Double Line error rate may be computed according to formula 4.6:

$$DLE = ER_{max} + [\sum_{j=1}^{2} (\frac{ER_j}{2}) - \frac{ER_{max}}{2}] = 0.22 + (\frac{0.39}{2} - \frac{0.22}{2}) \simeq \boxed{0.31}$$

In turn, according to formulae 4.7 and 4.8 the confidence intervals for each candidate output are computed. The pairs of higher and lower limits of the confidence interval for each candidate output have as follows:

$$\sum_{j=1}^{2} Cell_{1j} \pm DLE = -0.22 \pm 31\% \Rightarrow \begin{cases} pNVO_{1High} \simeq \boxed{\text{-0.15}} \\ pNVO_{1Low} \simeq \boxed{\text{-0.29}} \end{cases}$$

$$\sum_{j=1}^{2} Cell_{2j} \pm DLE = 0.22 \pm 31\% \Rightarrow \begin{cases} pNVO_{2High} \simeq \boxed{0.29} \\ pNVO_{2Low} \simeq \boxed{0.15} \end{cases}$$

$$\sum_{j=1}^{2} Cell_{3j} \pm DLE = 0.44 \pm 31\% \Rightarrow \begin{cases} pNVO_{3High} \simeq \boxed{0.58} \\ pNVO_{3Low} \simeq \boxed{0.30} \end{cases}$$

The survival threshold, defined as the lower limit of the maximum $pNVO$, is:

$$pNVO_{maxLow} = \boxed{0.30}$$

According to formula 4.9 the higher limits of all other candidates are compared with the survival threshold and the survivors are the ones whose higher limit is equal to, or greater than, the value of the threshold. Thus survivor from the Double Line is only **candidate 3 (maximum)**. All other candidates are killed (expelled from the rest of the process).

As long as there is only one survivor, the Double Line process may terminate and the survivor's sum of cell values is transformed directly in the set of final numeric values in order to be formally selected as optimal, according to the select function. Thus (trivially):

$$SelF(fNVO_3) = \boxed{1}$$

The semantic interpretation of the returned value is that **candidate output 3, decide in every case whether to mark or not, is optimal**. The fact that this is a rather rare phenomenon, if existing at all, should be attributed to the influence of the materialistic constraint in cases where the more elaborate conceptual constraint is of relatively negligible importance; at least this explanation is enforced by the placement of the Double Line before the DECISION constraint. As it is shown in the immediately following subsection, if the Double Line is removed (thus no grouping of constraints occurs), the optimal output is in accordance with widely observable behaviors.

All the above are summarized in the following evaluation tableau:

Constraints → **↓ Outputs**	CONF	MATL	**DOUBLE LINE**	DECI	**fNVO**
Never Mark	-0.89	0.67	{ −0.15 High −0.29 Low ⊗		
Always Mark	0.89	-0.67	{ 0.29 High 0.15 Low ⊗		
☞ Marking-Decision	0.44	0	{ 0.58 High <u>0.30</u> Low		0.44

The post-Double Line period

In the post-Double Line period the conceptual effort that is required in order for language users to decide whether they should mark human objects or not, is assumed to have become more apparent; consequently, user optimality entails that the conceptual effort has been a determinative factor for case marking, or not, human objects. This fact is reflected in the model by the removal of the Double Line, in order for candidate outputs to be evaluated in a single step with respect to all the constraints.

The analysis up to the evaluation function is identical to the one for the Double Line period; therefore the set of candidate outputs, the relative weights and, of course, the predictions considering the previously grouped before the Double Line constraints, are all the same. The only thing which needs to be added in order for the select step to function properly is the predictions regarding the DECISION constraint.

Outputs	DECI
Never Mark	++
Always Mark	+
Marking-Decision	−−

Case 2, post-Double Line period: Predictions for the conceptual effort constraint.

As long as no Double Line exists in this instance of the model, the evaluation takes place in terms of final numeric values. Final numeric values are calculated according to formula 4.4 (in this example, the non-numeric constraint variation of the formula), the only difference being that due to the absence of Double Lines instead of the cell values corresponding to the first k constraints before the Double Line, the cell values in the columns of all n constraints are summed up. Therefore, the final numeric values for each candidate output have as follows:

$$fNVO_1 = \sum_{j=1}^{3} (\frac{RW_1 \times DV_{1j}}{\sum_{j=1}^{3} RW}) = \boxed{0.22}$$

$$fNVO_2 = \sum_{j=1}^{3} (\frac{RW_2 \times DV_{2j}}{\sum_{j=1}^{3} RW}) = \boxed{\underline{0.44}}$$

$$fNVO_3 = \sum_{j=1}^{3} (\frac{RW_3 \times DV_{3j}}{\sum_{j=1}^{3} RW}) = \boxed{0}$$

Finally, according to the select function, optimal outputs are determined. Thus:

$$SelF(fNVO_i) = \begin{cases} 1 & \text{if max} \in \text{fNV} \\ 0 & \text{otherwise.} \end{cases}$$

$$SelF(fNVO_1) = 0 \;||\; SelF(fNVO_2) = \boxed{1} \;||\; SelF(fNVO_3) = 0$$

The semantic interpretation of the returned values is that **candidate output 2, always mark a human object, is optimal**. This optimal output, in connection with the output of the Double Line period, may be thought of as providing a historical, evolutionary explanation in the terms of Haspelmath; that is, hypothesizing that the marking-decision effort had been taken into account in subsequent evolutionary phases, the previous equilibrium of effort and efficiency became unstable, probably because the conjunction of the two types of effort was proven to be overwhelming for language users.

Therefore, user optimality in accordance with the ever present principle of minimum effort explains why the **"always mark"** behavior has turned out to be the optimal one: for it reduces the overall effort if the conceptual constraint is effectively taken into consideration, as it has been the theoretic assumption for the post Double Line period. All the above are summarized in the following evaluation tableau:

Constraints → **↓ Outputs**	CONF	MATL	DECI	**fNVO**
Never Mark	-0.89	0.67	0.44	0.22
☞ Always Mark	0.89	-0.67	0.22	<u>0.44</u>
Marking-Decision	0.44	0	-0.44	0

5.3 Case 3: Writing E-Mails in Greeklish

5.3.1 Case 3: Situational Setting

Originating from the days of the 7-bit ASCII code ($2^7 = 128$ characters, fairly enough for the Latin alphabet, but not for both Greek and Latin alphabets) there has been a common practice among Greek computer users to spell Greek words in Latin characters for computer mediated communication. This phenomenon came to be known as Greeklish.[11] Although the 8th bit in the ASCII code effectively solved the problem, various incompatibilities among different operating systems, as well as different code page encodings, increased the degree of uncertainty as to whether the recipient of an electronic message will be able to view properly Greek

[11] To be more accurate, the phenomenon of Greeklish, in its general form, concerns different aspects of the influence of the English language to the Greek one, such as extensive lexical borrowing, morpho-syntactic influences and direct importation of English words and expressions, much like the analogous phenomenon of *Franglais* with reference to the influence of English to French. In any case, especially after the invention of the Web which substantially increased the use of Internet as a means of communication among laymen, the orthographic aspect of the Greeklish phenomenon has attracted the interest of the academic community and became the main focus point on the issue.

characters. The sheer result has been that Greeklish turned out to be the main orthographic practice in e-mails and other related forms of communication (e.g. chat-room discussions, message-boards and, though exceptionally, webpages).

Due to the fact that the Greek language, being the main argument in favor of the direct origin of modern Greeks from the glorious ancient ancestors, is much more than a nationalistic fetish to modern Greeks, the case of Greeklish was not plainly attributed to the limitations of the technological factor, but, instead, became the field of serious academic dispute. During the recent years there has been a continually increasing literature over the phenomenon of Greeklish, some of which has been overtly polemical indeed.[12]

Furthermore, the case of Greeklish is problematic on its own account with respect to the type of transcription between the two alphabets. Although ELOT, the Greek standards' organization, provides a pattern for character correspondence, which is used in official documents as in the case of Latin alphabetized Greek names in passports, this pattern has not been adopted by the community of Greeklish users. Instead, three antagonistic models of transcription have emerged, all of which are more or less combined with each other in everyday practice:

- The optical model, which corresponds Greek characters to Latin ones according to similarities in the shape of characters, as in the cases of the numeral 3 for ξ, or of w for ω.
- The phonetic model, which corresponds characters according to phonetic values, as in the cases of ks for ξ, or of o for ω.
- The keyboard correspondence, according to which the placement of each character on the computer keyboard, following the old typewriter pattern, determines the correspondence, as in the cases of j for ξ, or of v for ω.

Therefore a word like $\xi\epsilon\rho\omega$ [(I) know] is optically transcribed as **3erw**, phonetically as **ksero**, or according to the keyboard matching as **jerv**.[13]

[12] A collection of articles and papers on the issue of Greeklish can be found in [Andro]. Unfortunately, although quite reasonably, the main corpus of this literature is in Greek.

[13] Surprisingly enough, despite the fact that the keyboard matching model produces the least legible morphemes in Greeklish, it is increasingly favored by teenage users. As long as, to the best of my knowledge, no research on this very specific aspect of the problem has been published yet, this observation should be regarded as an impressionistic one. This being the case, a possible explanation for this tendency is that computer educated users being accustomed to keyboard switches between the two alphabets find it easier to follow this pattern (thus minimizing effort), instead of following another model favoring the historical orthography of the Greek language, as the optical model.

This implementation of the FR-model regards the Greeklish phenomenon from the end-user point of view; yet the theoretic perspective is equally appropriate as for an explanation of the phenomenon in terms of efficiency in computer mediated communication, as far as the Greek language is concerned.

5.3.2 Case 3: Analysis

From all possible actions included in the solution space the *GEN* under the influence of the I.B.I. factor has generated the following set of candidate outputs:

1. Write e-mails in Greek (Greek alphabet).
2. Write e-mails in English (Latin alphabet).
3. Write e-mails in Greeklish (Greek in Latin alphabet).
4. Use image files (Greek characters in bitmaps).
5. Do not use e-mail for communication.

The members of the set of constraints, their interpretation, type, measurement method and units, and respective Relative Weights in hierarchical order are the following:

1. Name: AUDIENCE (AUDN)
   Interpretation: Target maximum audience
   Type: Non-Numeric
   Measurement: Degrees of Violation
   Relative Weight: 0.9
2. Name: EFFORT (EFRT)
   Interpretation: Minimize writing effort
   Type: Non-Numeric
   Measurement: Degrees of Violation
   Relative Weight: 0.7
3. Name: RESOURCES (RESR)
   Interpretation: Reserve computer resources and bandwidth (economy)
   Type: Non-Numeric
   Measurement: Degrees of Violation
   Relative Weight: 0.7
4. Name: LEGIBILITY (LEGB)
   Interpretation: Maximize legibility of messages
   Type: Non-Numeric

Measurement: Degrees of Violation
Relative Weight: 0.5

5. Name: TIME (TIME)
Interpretation: Minimize production time
Type: Non-Numeric
Measurement: Degrees of Violation
Relative Weight: 0.2

This example encounters one Double Line, positioned between the third and the fourth constraint. By this positioning of the Double Line constraints are grouped according to significance.[14] So the upper level of the efficiency and economy constraints as a group falls to the left of Double Line, whereas all the rest fall to the right.

Following the FR-model's procedural line, in the first step cell values are calculated only for the columns to the left of the Double Line. The interaction of constraints with the anticipated effects each candidate output may have to the respective measures gives rise to the following predictions:

Outputs	AUDN	EFRT	RESR
In Greek	−	+	+
In English	−	−	+
In Greeklish	++	−	+
Image Files	+	−−	−
No E-Mail	−−	++	++

Case 3: Predictions for group 1 constraints.

Values for the cells under non-numeric type constraints are calculated according to formula 4.3. The DV part of the numerator's expression is taken directly from the respective predictions and (the sum of the Relative Weights) $\sum_{j=1}^{5} RW = 3$. Thus:

[14]It is worth noting that, though acceptable in principle, a Double Line positioning between the second and the third constraint which have the same Relative Weight should be considered inconsistent as far as the significance of constraints is concerned.

$$Cell_{11} = \frac{0.9 \times (-1)}{3} = \boxed{\text{-0.30}} \quad Cell_{12} = \frac{0.7 \times 1}{3} \simeq \boxed{0.23} \quad Cell_{13} = \frac{0.7 \times 1}{3} \simeq \boxed{0.23}$$

$$Cell_{21} = \frac{0.9 \times (-1)}{3} = \boxed{\text{-0.30}} \quad Cell_{22} = \frac{0.7 \times (-1)}{3} \simeq \boxed{\text{-0.23}} \quad Cell_{23} = \frac{0.7 \times 1}{3} \simeq \boxed{0.23}$$

$$Cell_{31} = \frac{0.9 \times 2}{3} = \boxed{0.60} \quad Cell_{32} = \frac{0.7 \times (-1)}{3} \simeq \boxed{\text{-0.23}} \quad Cell_{33} = \frac{0.7 \times 1}{3} \simeq \boxed{0.23}$$

$$Cell_{41} = \frac{0.9 \times 1}{3} = \boxed{0.30} \quad Cell_{42} = \frac{0.7 \times (-2)}{3} \simeq \boxed{\text{-0.47}} \quad Cell_{43} = \frac{0.7 \times (-1)}{3} \simeq \boxed{\text{-0.23}}$$

$$Cell_{51} = \frac{0.9 \times (-2)}{3} = \boxed{\text{-0.60}} \quad Cell_{52} = \frac{0.7 \times 2}{3} = \boxed{0.47} \quad Cell_{53} = \frac{0.7 \times 2}{3} \simeq \boxed{0.47}$$

Given the $Cell\_Values$, formula 4.4 returns the partial numeric values for each candidate output i ($pNVO_i$) up to the Double Line by adding the $Cell\_Values$ in the respective row. In order to compute the confidence interval for each candidate the Double Line error rate is needed. The error rate for each constraint is calculated according to formula 4.5. Thus:

$$ER_1 = \frac{RW_1}{2 \times \sum_{j=1}^{5} RW} = \frac{0.9}{2 \times 3} = \boxed{0.15}$$

$$ER_2 = \frac{RW_2}{2 \times \sum_{j=1}^{5} RW} = \frac{0.7}{2 \times 3} \simeq \boxed{0.12}$$

$$ER_3 = \frac{RW_3}{2 \times \sum_{j=1}^{5} RW} = \frac{0.7}{2 \times 3} \simeq \boxed{0.12}$$

Therefore the Double Line error rate may be computed according to formula 4.6:

$$DLE = ER_{max} + [\sum_{j=1}^{3} (\frac{ER_j}{2}) - \frac{ER_{max}}{2}] = 0.15 + (\frac{0.39}{2} - \frac{0.15}{2}) = \boxed{0.27}$$

In turn, according to formulae 4.7 and 4.8 the confidence intervals for each candidate output are computed. The pairs of higher and lower limits of the confidence interval for each candidate output have as follows:

$$\sum_{j=1}^{3} Cell_{1j} \pm DLE = 0.16 \pm 27\% \Rightarrow \begin{cases} pNVO_{1High} \simeq \boxed{0.20} \\ pNVO_{1Low} \simeq \boxed{0.12} \end{cases}$$

$$\sum_{j=1}^{3} Cell_{2j} \pm DLE = -0.30 \pm 27\% \Rightarrow \begin{cases} pNVO_{2High} \simeq \boxed{-0.22} \\ pNVO_{2Low} \simeq \boxed{-0.38} \end{cases}$$

$$\sum_{j=1}^{3} Cell_{3j} \pm DLE = 0.60 \pm 27\% \Rightarrow \begin{cases} pNVO_{3High} \simeq \boxed{0.76} \\ pNVO_{3Low} \simeq \boxed{\underline{0.44}} \end{cases}$$

$$\sum_{j=1}^{3} Cell_{4j} \pm DLE = -0.49 \pm 27\% \Rightarrow \begin{cases} pNVO_{4High} \simeq \boxed{-0.29} \\ pNVO_{4Low} \simeq \boxed{-0.51} \end{cases}$$

$$\sum_{j=1}^{3} Cell_{5j} \pm DLE = 0.34 \pm 27\% \Rightarrow \begin{cases} pNVO_{5High} \simeq \boxed{0.041} \\ pNVO_{5Low} \simeq \boxed{0.025} \end{cases}$$

The survival threshold, defined as the lower limit of the maximum $pNVO$, is:

$$pNVO_{maxLow} = \boxed{0.44}$$

According to formula 4.9 the higher limits of all other candidates are compared with the survival threshold and the survivors are the ones whose higher limit is equal to, or greater than, the value of the threshold. Thus survivor from the Double Line is only **candidate 3 (maximum)**. All other candidates are killed (expelled from the rest of the process).

As long as there is only one survivor, the Double Line process may terminate and the survivor's sum of cell values is transformed directly in the set of final numeric values in order to be formally selected as optimal, according to the select function. Thus (trivially):

$$SelF(fNVO_3) = \boxed{1}$$

The semantic interpretation of the returned value is that **candidate output 3, write e-mails in Greeklish, is optimal**. Indeed, the observations support this result, for the use of Greeklish in e-mail and other forms of on-line communication has been a widespread practice all over the last decade and has eventually become a common trend, especially among Greek teenage computer users.

The Greeklish alternative, as an optimal output, also illustrates the feedback option of the model in its pure form: the optimal output triggers a new instance of the model and serves as a direct input. The new instance regards the type of transcription from the Greek to the Latin alphabet. As long as one has reach the decision of using Greeklish as the optimal orthographic solution for effective e-mail communication, one is simultaneously confronted with the alternative types of transcription mentioned in the preceding section (phonetic, optical, keyboard correspondence). Therefore the optimal output turns into a new input substantiating the feedback loop option. All of the above are summarized in the following tableau:

Constraints → **↓ Outputs**	AUDN	EFRT	RESR	DOUBLE LINE	LEGB	TIME	**fNVO**
In Greek	−0.30	0.23	0.23	0.20 High 0.12 Low			
In English	−0.30	−0.23	0.23	−0.22 High −0.38 Low			
☞ In Greeklish	0.60	−0.23	0.23	0.76 High 0.44 Low			0.60
Image Files	0.30	−0.47	−0.23	−0.29 High −0.51 Low			
No E-Mail	−0.60	0.47	0.47	0.41 High 0.25 Low			

Chapter 6

Epilogue

6.1 Conclusions

The main attempt of this paper was to reveal the similarities between common-sense decision-making tasks and the evaluation scheme employed under OT. The FR-model is the self-contained theoretic construction which (a) describes abstractly the procedural steps involved in evaluation processes in order to reach optimal outputs, and (b) provides the tools for practical implementations. As long as the model succeeds in determining optimal outputs following the (modified) OT selection process, within the limitations mentioned along the lines of the constructing definitions, it must be considered a strong indication of the close relation between OT and common-sense. If OT indeed conceptually captures everyday life's decision-making concerns under the notion of violable constraints, as it is the fundamental assumption underlying this paper, then, conclusively, the generalized transformed version presented inhere in the form of the FR-model fulfils the purposes for which it has been constructed in the first place and may be used as both a theoretic and an operational tool with reference to phenomena of cultural change.

Hence, the major conclusions to be drawn have as follows:

- The violability of constraints is shown to be the key-notion in the generalized version, as it is the case with standard OT. The modification according to which constraints may receive both negative and positive values, thus exhibiting cases of, so to speak, negative violability (or else fulfillment) enriches the functionality of the model and strengthens the relation with common-sense processes. The reason is that not all evaluating criteria in everyday life have the form of constraints to be avoided; instead, it is reasonably assumed that such criteria may take the form of tasks considered by the individual to increase happiness which have to be accomplished in maximum degree, in total agreement with classic utilitarianism.[1]

- A quite similar conclusion is to be drawn, *mutatis mutandis*, from the fact that candidate outputs in the FR-model yield numeric values (as far as numeric constraints -as defined above- are concerned). Moreover, numeric values significantly widen the field of the model's applicability because they provide an easy and clear quantification method to employ measurable constraints which otherwise would have to be disregarded as being dysfunctional (prominent examples are most of the constraints in the economy category). Taking a step backwards in order to view the whole picture and as long as the main task has been to construct a general, non-linguistic version of the OT mechanism, special attention has to be paid to the flexibility of the model, i.e. its ability to account for input problems from miscellaneous fields; as a conclusion, numeric values for candidate outputs make the model more flexible and facilitate the adaptive process with reference to specific tasks.

- One of the more difficult questions in the attempt to formalize selective processes concerns the preferences of the individual. The motivation behind the concept of the meta-constraint was exactly to capture, and by the assignment of Relative Weights to express in terms of quantification, the more or less subjective individual preferences. Two points may need to be reconsidered regarding the meta-constraint: (a) in the light of the fact that it is the DM-subject who assigns the values, one might argue that the model fails in actually capturing the individual preferences; true as this may be, the model still incorporates these values in the evaluation function, hence the individual preferences are finally computed and taken into consideration. (b) The issue, mentioned before, of the multi-dimensionality of the meta-constraint. In addition to the answer given in the respective section, it is true that more elaborate and detailed versions of the FR-model may resolve this issue more suitably, although with a considerable increase of the number of calculations which are required in order for the individual preferences to be computed as part of the evaluation function.

- With respect to the evaluation function *per se*, it should be clear that different calculation formulae may be invented in order to compute cell values and

[1]Cf. both the spirit and the letter in [RMi&Be] as well as in other classic texts of utilitarianism, most of which overemphasize maximization with respect to happiness-increasing activities.

determine the optimal outputs, under the following reservations:

1. The ranking of constraints should always reflect a significance hierarchy.
2. In the case of numeric constraints previous experiences should be incorporated in terms of quantification (a rate being strongly preferable over absolute values).
3. Evaluation in Double Lines should take into account all previous performance of each candidate output with respect to constraints on the left of the Double Line (but not to be retained afterwards).

The formulae which were actually presented as part of the proposed evaluation function satisfy all the above requirements and are relatively simple. Though more elaborate and technically advanced formulae were available, especially from the field of statistics as far as the ratio of survivors in Double Lines was concerned, the final formulae selection reflects both the similarity with the sharp techniques of standard OT and the emphasis given to the procedural over the computational aspect of the model.

6.2 Loop Remark

Hardly any features in the repertoire of human behaviors do not involve some kind of recurrent activity; optimal outputs, being behavioral patterns themselves, are no exceptions to the rule and the placement in the model of an optional feedback loop from optimal outputs to inputs and thereafter to optimal outputs again, provides the modelling solution to this side of human behavior.

Though of great interest as part of the construction process, the feedback loop differentiates only but a little the functionality of the model; this is the reason why the issue of the feedback loop only parenthetically has been addressed in the preceding chapters. In terms of procedure, optimal outputs return into the model as new inputs in two particular cases:

- After a period of time in a similar situational setting, in which case the change in the environment is of the type "new time", or
- In the immediately following time period if the optimal output is not a behavior in itself but rather a change of preferences which has to be substantiated as behavior with respect to a different, though related, situational setting.

In both cases, however, optimal outputs functioning as new inputs trigger new instances of the model just like any other input problem would do and the running of the model takes place normally. This is not the case with standard OT, in which the question between harmonic serialism (involving feedback loops) and harmonic parallelism (single, one off evaluations) remains more or less unresolved, as shown in [McCar].[2]

Still, the philosophical implications of the feedback loop deserve this final remark; for, though optional it may be, it is always an active alternative, serving as a reminder of the interrelation of human activities which affect each other continuously. Inputs and outputs may alter with respect to time, place and human subjects, but it is hard to imagine human actions which do not affect at least some tiny niche of human culture in whatever obscure manner. The feedback loop connects chronically and conceptually behaviors which result in cultural change; thus it symbolically depicts the continuous process which brings into being, in giant leaps or small steps, back and forth, all changes in the social environment. In every beat of the clock the ultimate output is our noisy human civilization.

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[2] In harmonic serialism harmonic outputs which are not considered ultimately optimal undergo further processing in the *GEN* until convergence is reached. "The essential difference between Harmonic Serialism and Harmonic Parallelism is that the former, but not the latter, recognizes intermediate outputs that may be distinct from the ultimate output." [McCar, p.2]. This explains the difference with the FR-model: as long as the model is concerned with actual cases of human behavior, no such thing as an intermediate output behavior may arise. The feedback loop results solely in new, although related, instances of the model.

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