Using an Interactive Evolutionary Algorithm to Help Fitting a Cochlear Implant

C. Bourgeois-Republique
LERSIA – Univ. de Bourgogne
bourgeois.republique@free.fr

Bruno Frachet
Hôp. Avicenne – Service ORL
bruno.frachet@avc.ap-hop-paris.fr

Pierre Collet
ULCO (Calais) – LIL
collet@lil.univ-littoral.fr

ABSTRACT

Cochlear implants are electronic devices that stimulate directly the auditory nerve to allow totally deaf patients to hear again. This paper presents an interactive evolutionary algorithm (IEA) designed to help finding the best parameters of a cochlear implant for a specific patient.

If early cochlear implants only featured one electrode, modern devices now offer up to 22 electrodes, with the hope to be able to transmit more details and help the patient hear better. The work presented in this paper shows however that having more electrodes is not necessarily better.

Tests on a patient show surprisingly that some combinations of electrodes yield better results than others, with the problem that there is no real way to determine which electrode is beneficial to speech understanding and which is not.

The best result obtained by the patient on a speech understanding evaluation protocol was 48.5/100 after 10 years of fitting sessions by an expert practitioner. For many reasons explained in this paper, the evaluation of the best parameter setting found by the IEA in one day was 91.5/100.

Categories and Subject Descriptors

G.1.6 [**Numerical Analysis**]: Optimization

General Terms

Experimentation

Keywords

Interactive evolutionary optimization, cochlear implants.

1. INTRODUCTION

Cochlear Implants (CI) allow totally deaf people to hear again provided their auditory nerve and cochlear are still functional: a computer processes sounds picked up from a microphone, to stimulate directly the auditory nerve through several electrodes inserted inside the cochlea.

As one can imagine, there are hundreds of parameters that can be tuned, hence the idea to use an interactive evolutionary algorithm (IEA) help with finding the best values for those parameters. A basic IEA was developed with this in mind, and tested on a very basic feature, the range of intensities a specific electrode can take when stimulating the auditory nerve.

This paper first presents cochlear implants and how they are tuned. Then the interactive evolutionary algorithm is described. It is tested on a willing patient, with impressive results. Hypotheses are tested and confirmed deterministically. Results are analysed, and the paper ends with important conclusions for the Cochlear Implants domain.

2. WHAT ARE COCHLEAR IMPLANTS ?

Research has been going on since nearly 50 years ago on how to electrically stimulate the auditory nerve to give a totally deaf patient sound sensations [6, 5].

Even though the early devices stimulated the auditory nerve with one electrode only, some lucky patients managed to hear again and even understand speech.

Many parameters could be tuned, and finding the best "fitting" was difficult since all patients are different (cause of deafness, number of years between total deafness and implantation, age, depth of electrode insertion,...).

Nowadays, it is technologically possible to use more than one electrode, in order to stimulate more of the thousands of neurons the auditory nerve is made of.

The cochlea is used to interface electrodes and the auditory nerve. The cochlea is a biological device that mainly allows to map different sound frequencies onto different neurons. It is shaped like a snail shell. Only long wavelengths (low frequency sounds) can reach the far end of the cochlea, while short wavelengths (high frequency sounds) are stopped at the entrance of the cochlea. The idea is then for surgeons to use this frequency discriminator and insert into the cochlea a thin silicon wire, bearing several electrodes.

Stimulating an electrode on the far end of the wire will therefore make the patient hear a low pitch sound, while stimulating an electrode near the entrance of the cochlea will result in the patient hearing a high pitch sound.

3. COCHLEAR IMPLANT FITTING

3.1 Many parameters to tune

Being able to use more than one electrode to stimulate different neuron areas is indeed a great improvement, but the number of parameters to tune increases drastically.

GECCO'05, June 25–29, 2005, Washington, DC, USA.

Concerning electrodes only, many questions arise :

- Which frequencies should be mapped to which electrodes ?
- Which range of intensities should be applied to which electrodes ?
- How many electrodes should be stimulated simultaneously ?
- Should the processor prohibit neighbour electrodes to be stimulated simultaneously in order to avoid diaphony (crosstalk between nearby electrodes) ?
- ...

3.2 Current method

Nowadays, depending on the manufacturer, the number of electrodes varies between 8 and 22. Cochlear Implant "fitting" is performed by an expert practitioner, who proceeds in the following way:

- Right after the surgical intervention, the practitioner tries to determine which electrodes are functional (an electrode is functional if the patient hears a sound when current is applied to the electrode).
- For each functional electrode, the practitioner tries to determine the range of intensities that can be used. The lowest intensity above which the patient perceives a sound is called T (for Threshold). The maximum confortable intensity (loudest sound the patient can bear for a reasonable amount of time) is called C (for Comfort threshold).

  Determining the T and C values for each electrode takes time (communication with a deaf patient, a young child, or with an old patient can be difficult), and due to the increasing number of electrodes, some manufacturers now advise to determine T and C values for one every three or four electrodes, and extrapolate the values for the other electrodes.

  Some other manufacturers even set average values for T and C, based on neural response or even statistics.
- Then, once the $C - T$ range is maximised for all the electrodes, the "real" fitting begins. The practitioner uses his expertise to map frequency bands logarithmically onto the different functional electrodes, and starts to tune the gain and sensitivity depending on sound frequencies, then tunes the number of simultaneously active electrodes,... while at he same time asking the patient whether they understand better or worse, whether the sound quality is comfortable or not, a.s.o. In certain cases, the practitioner will slightly reduce the $C-T$ range for some electrodes, when he has the feeling that the "neurologic" bandwidth is limited, and that the neurons facing the electrode are getting saturated at only moderate auditory levels.

Results range from patients who hear and understand everything perfectly after one or two fitting sessions, to patients who, after many sessions, cannot make anything out of the strange sounds they hear and prefer to switch off the processor.

Usually, a fitting session starts with the practitioner asking whether the current fitting is better or worse than the previous one. The best of the recent fittings is taken as a basis that the practitioner will try to improve, resulting in some sort of hill climbing process.

The patient tries to describe the quality of his audition, and the practitioner tries to modify some parameters to help solving the problems. Two or three parameters can be changed during a 30 to 90 minutes fitting session. Then, the patient leaves with the new settings that he keeps for a couple of months, before he comes back for another fitting session. The whole process is therefore very long (several years for problematic patients).

4. USING AN INTERACTIVE EVOLUTIONARY ALGORITHM AS AN AID

It seems that many patients who are not satisfied with their cochlear implant are stuck in a local optimum: no modification proposed by the expert would bring any improvement.

This triggered the idea to use evolutionary algorithms, that are both quite good at optimising parameters and not easily trapped in local optima.

Other works have been conducted on interactively fitting hearing aids with evolutionary algorithms, [2, 10, 11], but they concern only conventional hearing aids, with a relatively small number of parameters that can be tuned. To our knowledge, nobody has tried to apply evolutionary algorithms to Cochlear Implants fitting.

4.1 Interactive evaluation

Unfortunately, the algorithm needs to be interactive, meaning that results must be found with a very small number of evaluations [1, 9]. Standard evaluation protocols used by orthophonists take more than one hour to complete, and were therefore not useable as an evaluation function for an IEA. A new quick evaluation protocol had to be created.

Since the evaluation protocol is to be used on patients with hearing problems, it is essential that it is not too hard, so as to obtain a reasonable range of values. Two criteria need to be optimised: blind speech understanding (deaf people have a desperate need for communication) and comfort (an uncomfortable fitting will not be used by the patient).

In order to evaluate speech understanding, it was decided to use 10 calibrated sentences, made of 7 to 10 words, commonly used by orthophonists, as they contain a distribution of phonemes representative of the French language. The sentences contain 78 words, and one point is given for each recognised word. Then, the patient is asked to rate comfort on a 0 to 10 scale. This value is multiplied by 2.2 so as to get a range going from 0 to 22 which, when added to the number of recognised words, gives a total of 100. Therefore, comprehension counts for 78% of the mark, and comfort for 22%.

The genetic loop is the following: the EA "suggests" a set of parameters that are directly uploaded into the Cochlear Implant's processor, and waits for an evaluation.

The new evaluation protocol then begins. It is conducted by an assistant, who reads aloud the sentences to the patient, and notes the number of recognised words. (An evaluation software is currently developed to remove the assistant, so as to get as neutral a test as possible.)

The evaluation takes about 4mn to complete. The assistant types in the evaluation mark, and the algorithm suggests another set of parameters.

4.2 Setting up an evolutionary algorithm

It was decided to specify a simple algorithm using the EASEA language [3, 4], and improve it depending on how it would behave.

Genome structure Among the hundreds of parameters that can be modified, the expert practitioner suggested starting with determining the optimal T and C values for each electrode. In his experience, this was a good starting point as it would not totally change the perception of the patient, unlike changing frequency mapping for each electrode, for instance.

Before experimenting with the EA, the practitioner determines the maximum intensity range for each electrode, so as to define an envelope within which the evolutionary algorithm could suggest values. These values will be called T_e and C_e.

The genome structure is simply an array of $2 \times n$ floating point variables, representing the T and C values for each of the n electrodes of the implant.

Initialisation For each electrode, the T value is chosen at random between T_e and C_e, and the C value is chosen at random between T and C_e.

Crossover A simple 2 parents single point crossover is implemented, even though the genome is made of an array of real values. This choice comes from the fact that it did not seem very important to determine precise values for the T and C parameters: in deterministic tests, slight changes of the C and T values are not perceptible for the patient.

In this paper, many of the choices are not justified by thorough tests: It is not possible to conduct hundreds of experiments to help decide on different possibilities. Options were therefore chosen thanks to experience gathered in applying evolutionary techniques to other domains.

Mutation Each gene of the chromosome is mutated with a probability $P_{MutPerGene}$.

Mutating a gene simply consists in adding a random value between $[-2, 2]$. If mutating a T value gets it below T_e, the new value is set to T_e. Identically, if mutating a C value gets it over C_e, the new value is set to C_e.

Here again, nothing justifies this choice other than educated feeling. Other choices may prove to be better, and may be tried later on depending on the results obtained on the first patients.

Schwefel's adaptive mutation [8] has not been implemented. Applying this technique should allow to reduce the number of evaluations for equivalent results.

Evolutionary Engine As it is impossible to conduct many tests, the general guideline is to keep things simple and clean, be it only to be able to easily draw conclusions on the first experiments.

A simple ES+ (Evolutionary Strategy + [8]) is therefore implemented, with a binary tournament for parents selection and population replacement. Even though, in Evolution Strategies, mutation probability is quite high and crossover probability is quite low, experience suggests that in the present case, mutation probability should be quite low and crossover quite high: the number of evaluations is necessarily very small, meaning that premature convergence is not to be feared. On the contrary, rapid convergence is sought, so as to get interesting results in a small number of evaluations.

5. TESTING THE INTERACTIVE EA ON A "REAL" PATIENT

The primary objective of the first tests is to determine the best parameters for the interactive EA.

The described algorithm and evaluation procedure have been tested on a willing patient. The patient has received a 15 electrode MXM Digisonic implant 10 years ago, meaning that the genome structure will be an array of 30 real values. Unfortunately, he is not among the patients who immediately recovered a good audition. He can understand some words over the telephone, but communication is very difficult. He regularly goes to hospital for a fitting session, with the hope to improve speech understanding.

The envelope determined by the practitioner gives, for each electrode:

Electrode	1	2	3	4	5	6	7	8	9
Min	6	6.5	6.5	9	9	9	8	8	8
Max	9.5	13	13	18	20	21.5	21.5	18	16.5

Electrode	10	11	12	13	14	15			
Min	0	0	0	7	6	5			
Max	0	0	0	12	10	9			

T_e and C_e values for electrodes 10, 11 and 12 are null because these electrodes are not functional for the tested patient.

5.1 Evaluation of the expert's fitting

The fitting used by the patient on a daily basis (the best obtained by the expert practitioner over 10 years) gets an evaluation of 48.5, with less than 50% of understood words, and an average "comfort" mark of 5/10.

5.2 Experiments

Five runs have been performed on the patient for a total of 89 evaluations. Different algorithm parameters (population size, number of children per generation, ...) were tested.

5.2.0.1 *First run.*

The tested population size is 3 individuals, with 3 children per generation, tournament selection and replacement. Mutation rate is 0.1 and Xover rate is 1.

Fitting	1	2	3	4	5	6
Evaluation	44,2	21,2	9,2	31,4	55,6	46,4
Fitting	7	8	9	10	11	12
Evaluation	74,8	74,8	58,4	81	81	79,8

The 3 first fittings (individuals) have been generated randomly. Evaluation of the first individual gave 44.2, because 42 words were understood on a total of 78, and the patient gave a comfort mark of 1/10 only (the sound was resonating and feeling really uncomfortable) which, multiplied by 2.2 and added to 42 resulted in 44.2.

The other two individuals obtain quite poor evaluations.

Then, evolution starts at fitting 4, with three children per generation (generations are marked with double bars), one of which obtains a great evaluation of 55.6 (higher than what was obtained by the expert).

Then on the third and fourth generations, values around 80 are obtained, which is very surprising. The evaluation of the three individuals of the fourth generation is nearly identical, which suggests premature convergence (the tested evolutionary algorithm is very simple, with only 3 individuals and does not implement any tricks to preserve diversity).

The aim of the tests being to find good parameters for the evolutionary engine, the run is stopped and a larger population size is tried.

The run has taken about one hour to complete, and the patient is enthusiastic.

5.2.0.2 Second run.

In order to delay convergence, the new parameters for the interactive EA are a population of 6 individuals, with 4 children per generation.

Fitting	1	2	3	4	5	6	7	8	9	10
Evaluation	24	17	30	19	53	37	22	24	33	32
Fitting	11	12	13	14	15	16	17	–	–	–
Evaluation	9	27	34	34	12	27	32	–	–	–

Among the 6 first random individuals, one obtains an evaluation of 53.2, which is higher than what the expert practitioner ever obtained in ten years of fitting sessions. This is really surprising and will be investigated below.

The IEA is not as successful as on the first run, with values around 30 and some really poor individuals (11 and 15, which obtain evaluations of 9 and 12), probably due to both a too large population and number of children per generation.

The patient gets tired and disappointed and the run is stopped after the 17th evaluation.

5.2.0.3 Third run.

Population size is brought back to 3 individuals, with 2 children per generation. Mutation rate is increased to 0.6 to favour exploration and a roulette-wheel parents selector is tested (rather than a binary tournament) to increase selective pressure.

F.	1	2	3	4	5	6	7	8	9	10	11
E.	54	33	26	48	52	51	54	62	59	65	60
F.	12	13	14	15	16	17	18	19	20	21	22
E.	60	72	69	53	73	67	50	62	68	67	65

The three initial individuals obtain good values. Then, the second generation obtains values near 50 that keep increasing towards 70.

The evaluations of the latest generations seem to stabilise around 67, while the best individual (73). was obtained at evaluation 16.

5.2.0.4 Fourth run.

Population size is set to four individuals and four children per generation. Mutation rate is brought back to 0.1 and parents selection is set back to Tournament.

Fitting	1	2	3	4	5	6	7	8
Evaluation	59.4	62.2	57.3	58.9	57	62.3	65	73
Fitting 9	10	11	12	13	14	15	16	
Evaluation	75.3	65.2	83.1	68	75.4	91	91.5	

The first random individuals are all very good, and evaluation increases up to 91.5, with nearly all recognised words albeit with a poor confort mark.

It is time for lunch, so the run is stopped. The patient is now tired, but extremely satisfied and surprised by such results.

5.2.0.5 Fifth run.

A fifth run is conducted after lunch. Population size is set to five individuals, with two children per generation.

F	1	2	3	4	5	6	7	8	9	10	11
E	18	53	70	9	71	58	60	58	51	57	48
F	12	13	14	15	16	17	18	19	20	21	22
E	36	36	50	29	33	50	40	44	48	49	45

Two of the first five randomly generated individuals obtain evaluations over 70. Unfortunately, artificial evolution does not find any better individuals and the run is stopped at evaluation 22.

6. DISCUSSION ON OBTAINED RESULTS

6.1 Fitness evolution

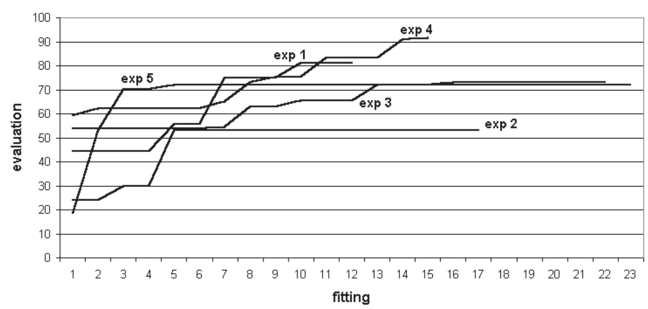

Figure 1: Fitness of the best individual for the five runs

The evolution of the best individual for each of the runs is shown fig. 1. Fitness increases on all experiments but exp. 2, which is a nice result for such a small number of evaluations, meaning that the educated guesses made on the IEA implementation were probably good.

It seems that the correct population size is 3 or 4 individuals, with 2 to 4 children per generation.

6.2 Analysis of the best obtained individual

Analysis of the T/C values of the best individual is intriguing (cf. fig. 2):

(Electrodes 10, 11 and 12 have been omitted as they are not functional.)

Sometimes, experts reduce the $C-T$ range for some electrodes when they feel that the neural "bandwidth" is too narrow and there is a possibility of saturation if the auditory information is too important.

In the fitting found by the IEA, however, many of the $C-T$ ranges are reduced down to 1.5, 1, 0.5 and even 0. In

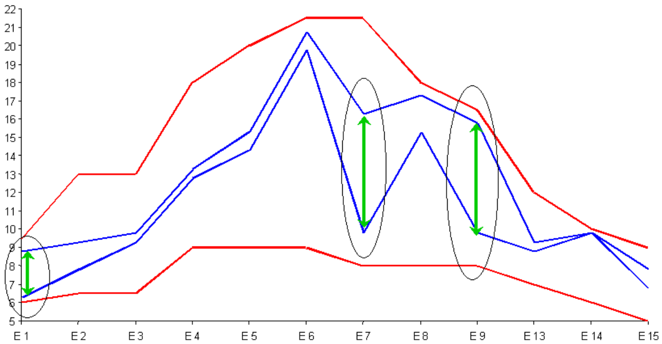

Figure 2: Maximum allowed envelope and the best obtained individual.

fact, only electrodes 1, 7 and 9 have significant ranges (over 2.5).

Other good fittings show wider ranges for electrodes 7 and 9 and narrower ranges for the other electrodes, which raises a hypothesis: What if, for this precise patient, some electrodes had a negative influence on speech understanding ?

If this were the case, the current practice (that has been going on for many years) of maximising the range of as many electrodes as possible would also maximise the range of "wrong" electrodes that prevent the patient of understanding speech.

After this first evolutionary fitting session, the patient went back home with the original settings in his CI.

7. TESTING HYPOTHESES DETERMINISTICALLY

One month later, a set of tests were performed in order to check some hypotheses.

7.1 Checking electrodes 1, 7 and 9

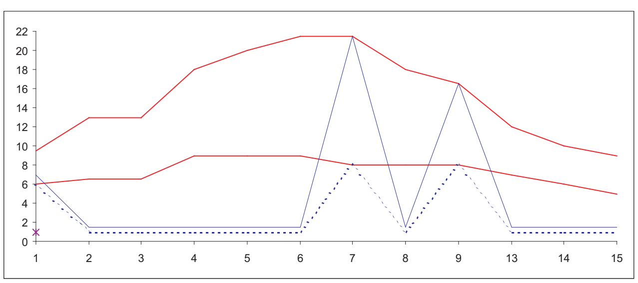

Figure 3: Testing with electrodes 1, 7 and 9 only. The bold curves represent the envelope (T_e and C_e) for each electrode.

Surprisingly enough, the best individual obtained during the fourth run was virtually using only three of the 12 functional electrodes (electrodes 1, 7 and 9), that could be reduced to only 2, since electrode 1 was mapped onto very low frequency sounds that are not discriminant for speech.

In order to confirm this strange result, the first deterministic test maximises electrodes 7 and 9 only (using the maximum $C_e - T_e$ range), giving only a small range to electrode 1 (cf. fig. 3). For all the other electrodes, T and C values are set to 1 and 1.5, i.e. much below the T_e threshold, in order to cancel them totally. This setting obtains an evaluation of 82, which is much better than with all activated electrodes (best fitting of 48.5 obtained by the expert). Nearly 90% of the words were understood, and the fitting was rated as not very comfortable.

This allows to conclude that for this patient, using only three electrodes out of 15 allows him to understand speech better than with all functional electrodes set to nearly maximum range.

7.2 Checking for diaphony

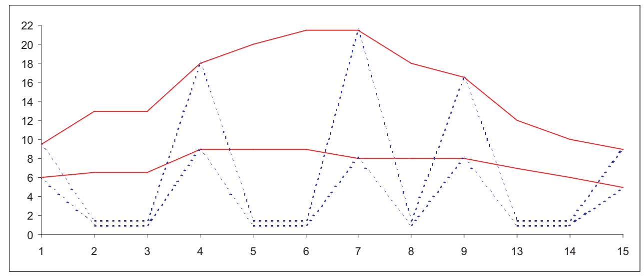

Figure 4: Checking for diaphony by selecting only one every 3 electrodes, and keeping electrode 9.

Another hypothesis suggested by Pr. Frachet is diaphony (crosstalk) between close electrodes. In order to check this hypothesis, 2 electrodes out of 3 are cancelled, by setting their T and C values to 1 and 1.5 (cf. fig. 4).

Therefore, electrodes 1, 4, 7 are activated. It was chosen to keep electrode 9 active, so as to keep a common comparison basis with the previous experiments. Finally, electrode 15 is maximised (cf. fig. 4).

This fitting obtains an evaluation of only 58.5, i.e. clearly not as good as the previous ones, and the patient rates it as quite uncomfortable. This is very surprising, as the only difference with the first test (that had obtained an evaluation of 82) is that electrodes 4 and 15 have been added.

Clearly, not only is there no diaphony problem (spacing active electrodes did not improve evaluation), but it can be concluded that for this patient, electrodes 4 and 15 *contribute negatively to speech understanding*. The fact that functional electrodes can contribute negatively to speech understanding is a totally new concept in the cochlear implant medical field.

7.3 Other tests

Other tests were conducted, that activated randomly chosen electrodes.

Results were average to low, and rated from incomfortable to very incomfortable by the patient. The conclusion of these tests is that it is not easy to find really good results by randomly activating or deactivating electrodes using their full $C - T$ range.

At the end of the session, the original fitting found by the expert was evaluated again and obtained only 41.8 (against 48.5 one month before). Then, the best obtained individual of run 4 was tested again and obtained 86.2 (against 91.5 one month before). This was the best value obtained during this second session.

This shows that the fast evaluation method elaborated for the IEA is efficient and yields reproductible results.

8. RESULTS ANALYSIS

For this patient, everything leads to think that the problem is combinatorial: some combinations of electrodes work better than others.

Combinatorially speaking, there are $2^{12} = 4096$ different ways of combining the 12 functional electrodes of this patient. Without any hint on which electrodes are positively or negatively affecting comprehension, a practitioner has virtually no chance to find an optimal combination at 30+ minutes per manual setting and evaluation. Worse: practitioners never try to find a good combination, as they all maximise all electrodes by default, based on the idea that the more electrodes the better.

With the small basic interactive EA presented above, 89 tests were conducted in one day, but a lot of time was lost in setting up everything, as it was the first time such an experiment was ever attempted.

Supposing 100 evaluations had been performed, the chance to have found the optimal combination would have been 1 over 40 only, and over much less if (as it seems to be the case) several combinations lead to very good evaluations.

The basic evolutionary algorithm that was used had parameters tuned to favour quick convergence. Three out of the five runs converge rapidly on fittings that evaluate differently (cf. fig. 1). The evolutionary algorithm is therefore more used as an exploitation method on a complex non-linear problem than as an exploration method, with a periodic restart used for exploration. This mechanism is nice because the patient sees some improvement between the evaluation, and once convergence has occurred, the restart allows for a break that gives a bit of rest to the patient.

A random search would have been psychologically very tiring for the patient (no obvious progress during the run) and interesting valleys would not have been exploited.

In 100 tests, a random search would have had one chance over 40 to find the best setting. All in all, the challenge was not that immense for an IEA, that can do much better than a random search if it is well adapted to the problem at hand.

Things will get much more interesting when the algorithm is tested on patients with more functional electrodes, as adding more electrodes leads to a combinatorial explosion (with 15 electrodes, the number of different combinations is $2^{15} = 32768$, and with 22 electrodes, 2^{22} is more than 4 million !).

9. CONCLUSION AND DEVELOPMENTS

Even though basic mathematics show that the probability to find a very good fitting was high with 89 evaluations conducted by an IEA, many very important conclusions came out from this work, although mostly in the medical area:

1. To start with, the common idea among orthophonists that a new fitting can only be evaluated after several days, by extensive tests taking at least one hour is invalidated by this series of experiments: a very good fitting has been found thanks to a 4mn evaluation procedure that was tested by the patient only seconds after the new parameters were changed in the processor.

2. Results were reproductible after one month, meaning that the very fast evaluation procedure was not very noisy.

3. 89 different settings were tested in one day, which is again something that was considered impossible by practitioners.

4. For this patient, the evaluation protocol was too simple, as values of 90/100 were quickly reached, beyond which it is difficult to go. A new harder protocol must be designed, based on lists of words and not sentences, so that the patient can guide evolution towards even better settings.

5. Some functional electrodes can contribute negatively to speech understanding !

   The common practice among practitioners to maximise the $C-T$ range of all functional electrodes was far from being optimal for this patient (this is a euphemism: many random individuals came up with much better evaluations than what the practitioner had obtained after 10 years of fitting sessions). Of course, this must be further investigated with many more patients, but if determining T and C values is really so crucial, what many cochlear implants manufacturers are advising is totally wrong. The trend is nowadays to evaluate the T and C values for one every 3 or 4 electrodes and extrapolate the values for untested electrodes, to save on time. In the software of a particular manufacturer, the practitioner cannot even change T and C values which are set to average values by default !

6. For this patient, the problem is combinatorial, with certain combinations of electrodes giving good results, and other giving bad results. If practitioners can easily determine whether an electrode is functional or not, they seem to be totally incapable to detect whether an electrode is positively or negatively affecting speech understanding. This makes it impossible for them to find the right combination of electrodes, due to the sheer number of tests they would need to conduct by hand (32 768 different combinations for 15 electrodes, and a single practitioner-driven test takes more than 20mn).

Even if these conclusions impact more the Cochlear Implant domain than EAs, they were obtained thanks to an interactive EA which, in order to be used, imposed to try out the unthinkable, i.e. testing nearly 100 different fittings in one day, where the common practice is to adjust a small number of parameters 3 to 5 times a year, based on the common idea that it is impossible to evaluate a new fitting less than several days after the change, and using anything quicker than a one hour thorough evaluation of the audition.

Having no preconceived ideas made it possible for the EA to come up with great individuals the analysis of which showed that some electrodes could have a negative influence on speech understanding.

The most important result of this work is however the improvement of the patient's ability to communicate. After the second test session, he voluntarily left with the new parameters, leading to one more confirmation of something practitioners were suspecting, but never really applied: after one week, the patient came to find the new settings quite comfortable, thanks to the plasticity of his biological neural network. This is again something practitioners do not generally do: whenever they find parameters that improve the patient's understanding to the expense of comfort, they often back out as they do not dare to have a patient leave hospital with an uncomfortable setting.

One month after the patient chose to keep the best fitting found by the IEA, his relatives and friends keep telling him they are surprised at how well he can understand them (which is a much better evaluation than a list of words).

A project called HEVEA has been set up to continue the development of an automatic fitting software for cochlear implants based on interactive evolutionary algorithms. The project has obtained a fund from the French government.

Tests with more patients (30 patients at least) will begin within a few weeks, and the crude (but nevertheless efficient) algorithm presented in this paper will be refined as more experiments are conducted with different patients.

An automatic evaluation software is under development that will enable to avoid using a human assistant to conduct the evaluations, which may bias the results.

10. ACKNOWLEDGEMENTS

Many thanks to Yves Ormezzano, expert practitioner, to MXM Labs [7] for their cooperation and to René Bérigaud, a very patient patient.

11. REFERENCES

[1] Banzhaf W, "Handbook of Evolutionary Computation" (chapter on Interactive Evolution) *Oxford University Press* 1997.

[2] Durant, E. A., *Hearing Aid Fitting with Genetic Algorithms*, PHD Thesis, University of Michigan, USA 2002

[3] Pierre Collet, Evelyne Lutton, Marc Schoenauer, and Jean Louchet, "Take it EASEA," *Lecture Notes in Computer Science*, 1917:891-901, 2000.

[4] Pierre Collet. Easea language, 2004. http://sourceforge.net/projects/easea.

[5] Loizou P., "Mimicking the Human Ear," IEEE Signal Processing Magazine, 15(5), 101-130, 1998.

[6] Loizou P., Poroy O., Dorman M.,"The Effect of Parametric Variations of Cochlear Implant Processors on Speech Understanding," *Journal of Acoustical Society of America*, 2000, pp790-802.

[7] MXM Laboratories, `http://mxmlab.com`.

[8] Schwefel H.-P., *Numerical Optimization of Computer Models*. Second edition. John Wiley & Sons, 1995.

[9] Takagi, H., "Interactive Evolutionary Computation : System Optimisation Based on Human Subjective Evaluation," Proceedings of the IEEE Intelligent Engineering Systems (INES'98) Vienna, Austria, 1998.

[10] Ohsaki M., Sakamoto S., Takagi H., "Development and Evaluation of an IEC Fitting System for Hearing Aids," International Conference on Acoustics (ICA2001), Rome, Italy, 5A.15.02 (Sept. 2-7, 2001).

[11] Takagi, H., "Interactive Evolution Computation: Fusion of the Capabilities of EC Optimization and Human Evaluation," Proceedings of the IEEE, Vol. 89, No 9, Sept 2002, pp 1275-1296.