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ALICE
Aston Lab for Intelligent Collectives Engineering

Modelling and Optimization of Non-Linear Complex Systems

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Biopic

- BSc in Mathematics
- MSc in Pure Math: Topology and Dynamic Systems
- PhD in Electrical Engineering

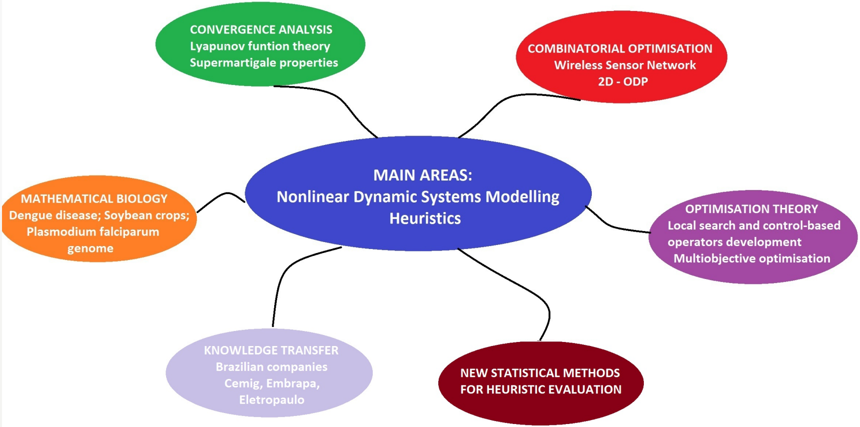
Actual position

- Senior Lecturer - Dept of Computer Science
- Deputy HoD

Research Activities

- Multi-disciplinary group: ALICE
- Inter-departmental cooperation
- Collaborations: UFMG, UFOP, LNCC, USP, Portugal, UK (Manchester, Sheffield, York), Germany, Belgium
- Collaborative work with some industries: CEMIG, EMBRAPA, ARCUS, Smart Apprentices

Research Areas of Interest



Agenda

- Dengue Control
- Phoneme Aware Speech Recognition
- The Security Constrained Optimal Power Flow Problem
- Optimization Algorithm Design

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- Major public health problem in tropical and subtropical regions around the world.
- 3.9 billion of human beings lived in risky regions, 390 million of infections per year (WHO).
- Brazil: an important epidemic disease; the most important viral disease (WHO).

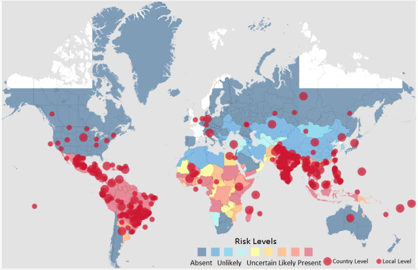
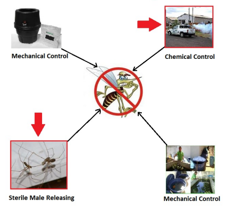


Figure: *Centers for Disease Control and Prevention, 2018*

Life cycle of *Aedes aegypti*

- Two stages: **immature** (eggs, larvae and pupae) and **adult** (adult mosquitoes)
- Females lay eggs in standing water;
- Humans are infected when bitten by feeding infectious females;
- Suceptible mosquitoes infected when feeding on infectious humans.



- **Chemical control**:
  - pesticide
- **Biological Control**:
  - sterile males
- Cost: **U$ 500 m/year**

$\Longrightarrow$ **To combine pesticide control with sterile male technique**

Mathematical Model with Control Action

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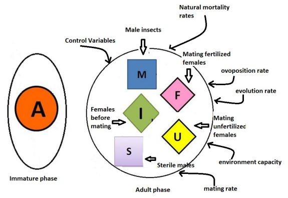
Mathematical Model to analyse the economic cost of these controls:



Cost Function:

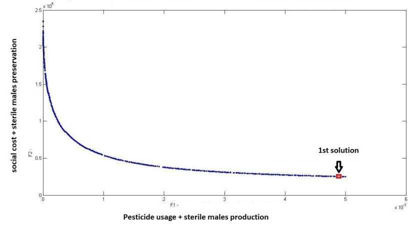
$$J[u] = \frac{1}{2}\int_0^T (c_1 u_1^2 + c_2 u_2^2 + c_3 F^2 - c_4 S^2)dt$$

- c_1 pesticide cost
- c_2 sterile males production cost
- c_3 social cost
- c_4 sterile males preservation cost
- **Current situation**:
  - low values (c_1 c_4), very high value (c_3), high value (c_2)
- **Control variables**: constant in time

Results

- **Using only one cost function**:
  - Obtained result is almost 100% better than the previous results
  - Obtained policy: releasing less sterile males in the environment and using the same amount of pesticide
  - Conclusion: minimization of the economic cost but with a reduced benefit for the society

- **Using two different cost function**



- **Voice Assistants**:
  - Many applications
  - Increasing worldwide usage
  - Several language-dependent key issues
    - Finnish, Italian and Spanish: simple
    - English: not really!
- **GOAL:** an approach to speech recognition via the phonemic structure of the morphemes rather than classical word and phrase recognition techniques

The Speech Recognition Problem

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- Acoustic signals analysed and structured into a hierarchy of units
  - phonemes, words, phrases and sentences
- Source of variability:
  - pronunciation
  - accent
  - articulation
  - nasality

- Spelling issues
  - same sound: many letters or combination of letters (he and people)
  - same letter: a variety of sounds (father and many)
  - a combination of letters: a single sound (shoot and character)
  - a single letter: a combination of sounds (xerox)
  - some letters not pronounced at all (sword and psychology)
  - no letter representing a sound (cute)

Diphthong vowels in spoken English

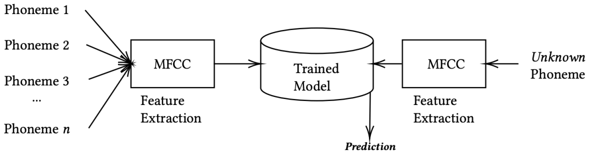
Symbol	English Example
ɪə	**Near**, **ear**, cl**ear**, f**ear**
eə	H**air**, th**ere**, c**are**
eɪ	F**a**ce, sp**a**ce, r**ai**n, c**a**se, **eigh**t
ɔɪ	J**oy**, empl**oy**, t**oy**, **oy**ster.
aɪ	M**y**, s**igh**t, pr**i**de, k**i**nd, fl**igh**t
əʊ	N**o**, d**o**n't, st**o**ne, al**o**ne
aʊ	M**ou**th, h**ou**se, br**ow**n, c**ow**, **ou**t

- Pronunciation of foreign words with a local dialect replaces its natural phonetic structure
  - phoneme errors seriously degrade the intelligibility of speech

- **Main Idea:** to classify phonemes in speech, considering their temporal occurrence and transcribe the speech even with words unseen due to the retention of the word's phonetics
- **Methodology**
  - Data Collection and Attribute Generation
    - audio recordings of diphthong vowels gathered
    - seven phonemes, ten times each, 420 individual clips
    - sliding window introduced to extract the Mel-Frequency Cepstral Coeficient data from audio

Gender	Age	Accent Locale
M	22	West Midlands, UK
F	19	West Midlands, UK
F	32	London, UK
M	24	Mexico City, MX
F	58	Mexico City, MX
M	23	Chihuahua, MX

- Training and Prediction phase



  - 10-fold cross validation
  - overall accuracy
  - 500 epochs of training time
  - learning rate of 0.3 and a momentum of 0.2.
- Accuracy Maximisation
  - optimising the MLP ANN using the DEvo approach
    - number of layers $[1, 5]$
    - number of neurons in each layer $[1, 100]$

A Comparison Model Training Time for Produced Models Post-Search

- **Hidden Markov Model**
  - 25: 25: 175 hidden units
  - 150 hidden unit: best accuracy result (86.23%)
- **Obtained Topologies**
  - $S1$: L (1); N (21); A (87.5%)
  - $S2$: L (1); N (25); A (88.3%)
  - $S3$: L (3); N (30, 7, 29); A (88.84%)
- **Time in Cross-Validation**
  - # of layers increases (1 $\rightarrow$ 3) from one to three, the accuracy increases (88.3% $\rightarrow$ 88.84%) and time increases (720.71 s $\rightarrow$ 1,460.44 s)
- **Advantage?**
  - one hidden layer
    - $S4$, $S5$ and $S6$ $\rightarrow$ 57, 50 and 51 N

CE+EPSO: a merged approach to solve SCOPF problem

- Large-scale global optimization (LSGO) problems:
  - practical applications: aerospace, biomedicine and power systems
  - difficulty in finding the optimum in high-dimensional spaces
- 2018 Competition & Panel: Emerging heuristic optimization algorithms for operational planning of sustainable electrical power systems

- find the most promising algorithm
- new insights on how to tackle these problems
- solve the benchmarks as black-box problems

IEEE PES
Power & Energy Society™

- **Test bed 1**: Stochastic OPF in Presence of Renewable Energy and Controllable Loads
  - CE + EPSO (Cross-Entropy Method and Evolutionary Particle Swarm Optimization)
  - EE-CMAES (Entropy Enhanced Covariance Matrix Adaptation Evolution Strategy)
- **Test bed 2**: Dynamic OPF in Presence of Renewable Energy and Electric Vehicles
  - CE + EPSO (Cross-Entropy Method and Evolutionary Particle Swarm Optimization)
  - SNA (Shrinking Net Algorithm)

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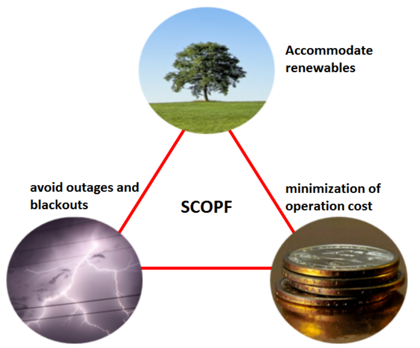
The Security Constrained Optimal Power Flow (SCOPF) Problem

- a nonlinear, non-convex, LSGO
- continuous and discrete variables
- tool for many transmission system operators: planning, operational planning and real-time operation
- balancing the *greed*, the *fear* and the *green*

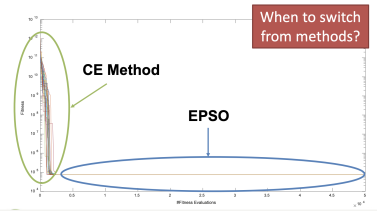


Structure of the optimization problem

- Objective function
  - minimization of operational cost
- Equality constraints
  - Physical flows in the network (power flow)
- Inequality constraints
  - Safety margin to provide stability, reliability
- $N - 1$ Security Criterion
  - System with N components should be able to continue operating after any single outage

Approach

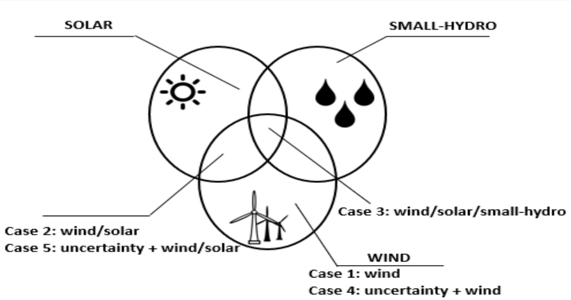
- Combination of two optimization methods
  - Cross Entropy (CE) method: exploration
  - Evolutionary Particle Swarm Optimization (EPSO): exploitation
- **Challenge:** Switch from CE method to EPSO



1. Trial & Error
2. Track the rate of improvement of the best fitness, switch when the rate becomes inferior a given threshold
3. Monitor the variance of the CE Method sampling distributions
   - variance can decrease very slowly without affecting the function

Test Bed A:

- Feasible solutions are difficult to obtain since the production in each period can be highly conditioned by the production in the adjacent periods
- Combinations of renewable energy sources and controllable loads:



Results for Test Bed A (in $/h)

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		Best	Worst	Mean
Case 1	CE+EPSO	80.732,46	81.547,19	81.077,07
Case 2	CE+EPSO	67.709,06	68.923,91	68.473,43
Case 3	CE+EPSO	55.245,86	56.683,60	55.935,62
Case 4	CE+EPSO	84.382,21	84.880,76	84.442,94
Case 5	CE+EPSO	71.044,22	71.128,74	71.065,91
Total cost	CE+EPSO	**359.113,81**	363.164,20	**360.994,97**
	EE-CMAES	360.211,11	**361.990,28**	361.326,93

In an annual projection, CE+EPSO saves approximately **US $3 million** compared to EE-CMAES.

Test Bed B:

- The electric vehicles are dissociable units (V2G or G2V)
- Total fuel cost of traditional generators, the expected uncertainty cost for renewable energy generators and the uncertainty cost for electric vehicles
- 6×130 optimization variables: 107 c, 9 d and 14 b
- 492 constraints for each N-1 contingency condition

Results of Test Bed (B) (in \$/h):

		Best	Worst	Mean
Test Bed 2	CE+EPSO	**773.193,77**	**823.684,44**	**789.719,58**
	SNA	1.172.100,00	1.878.123,00	1.518.700,00

Nature-inspired metaheuristics:

- Historically
  - Metaphor-driven design
  - New mechanisms or operator accompanied by new parameters
  - Performance not the main concern
- Currently
  - Practice emphasises *raw* performance, hard problems, very elaborate algorithms - not amenable to analysis...

BIG GAP

  - Theory emphasises *asymptotic* behaviour, easy problems, very simple algorithms - not competitive in practice...

Most optimization algorithms are deterministic discrete dynamical systems:

$$x_{t+1} = F(t, x_t, u_t)$$

where:

- $t \in \mathbb{N}$ is the time (or iteration) index
- x_t S is the system state (vector) at time t
- S is the state space
- $u_t \in \mathbb{R}^p$ is, a possible random, input vector (of size p)
- $F : \mathbb{N} \times S \times \mathbb{R}^p \leftarrow S$ is the state-transition function

If there is a point x^* such that $F(t, x^*, u) = x^*$ for all $t \in \mathbb{N}$ and a constant input u, it is called a *point of equilibrium* of the system (for that input).

Parameter Tuning

- Algorithm parameters subject to online adaptation become state variables of the algorithm
- Typically, new (static) parameters are introduced, such as adaptation rates
- In the presence of random inputs, the state becomes a stochastic process
- The control design problem consists in determining the (fixed) parameters that minimize some cost function of the system state trajectory
- Analysis requires that the algorithm be designed with tractability in mind
- Solving the control design problem numerically is perfectly acceptable

Adaptive $(1, \lambda)$-ES Formulation

$$
\begin{aligned}
x_{t+1} &= F(x_t, d_t, \mu_{1,t+1}, \ldots, \mu_{\lambda,t+1}) \\
&= \operatorname*{arg\,min}_{x \in \left\{x_{i,t} = x_t + \mu_{i,t+1} d_t,\ i=1,\ldots,\lambda\right\}} f(x) \\
d_{t+1} &= G(x_t, d_t, \mu_{1,t+1}, \ldots, \mu_{\lambda,t+1}) \\
&= \begin{cases} \alpha_f \cdot d_t \text{ if } f(x_{t+1}) > f(x_t) \\ \alpha_s \cdot d_t \text{ if } f(x_{t+1}) \leq f(x_t) \end{cases}
\end{aligned}
$$

$x_t \in \mathbb{R},\ d_t \in]0, +\infty[$

$u_{1,t}, \cdots, u_{\lambda,t} \approx \mathcal{U}(-1, 1)$

$\alpha_s \in [1, +\infty[,\ d_t \in]0, +\infty[$

- The sphere model is considered in the analysis. In particular, $f(x) = |x|$.

Rate of Convergence

In this case, a Lyapunov synthesis procedure amounts to maximizing a constant a, such that:

$$E^{A_t}(V_{t+1}) \leq V_t - a$$

for all x_t and d_t, where

$$V_t = V(x_t, d_t) = ln(|x_t| + wd_t) - k \; ln(d_t)$$

$w, k \in \mathbb{R}$, $w > 0$, and $0 < k < 1$.

- The Lyapunov function $V(x_t, d_t)$ is such that convergence of V_t to $-\infty$ implies convergence of $|x_t|$ to the minimum of $f(x)$ and of d_t to zero.
- Algebraic manipulation of the condition $E^{A_t}(V_{t+1}) \leq V_t - a$ leads to a constrained non-linear programming problem that can be solved numerically.

$$(\alpha_s^*, \alpha_f^*, w^*, k^*, a^*) = \underset{\alpha_s, \alpha_f, w, k, a}{\arg\max} \; a$$

$$\text{subject to: } \begin{cases} \alpha_s \geq 1 \\ 0 < \alpha_f \leq 1 \\ w > 0 \\ 0 \leq k < 1 \\ \Psi(r) + a \leq 0, \quad r = 0, 1/2, 1, +\infty \\ \Psi(r^*) + a \leq 0, \quad r^* : \Psi'(r^*) = 0 \end{cases}$$

where $\Psi(r)$, its derivatives and stationary points can be determined analitically.

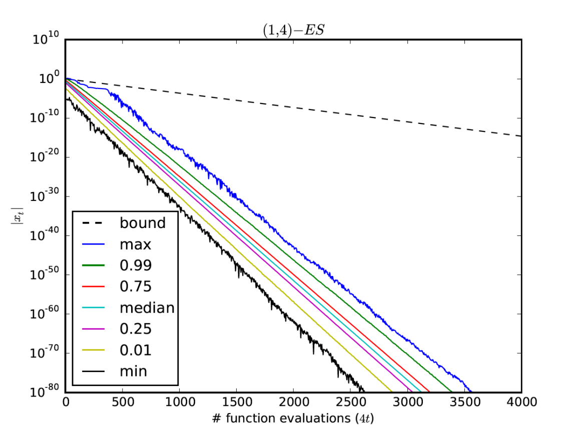
As an example, for $\alpha = 4$:

$$\alpha_s^* = 1.19591 \qquad \alpha_f^* = 0.42236$$

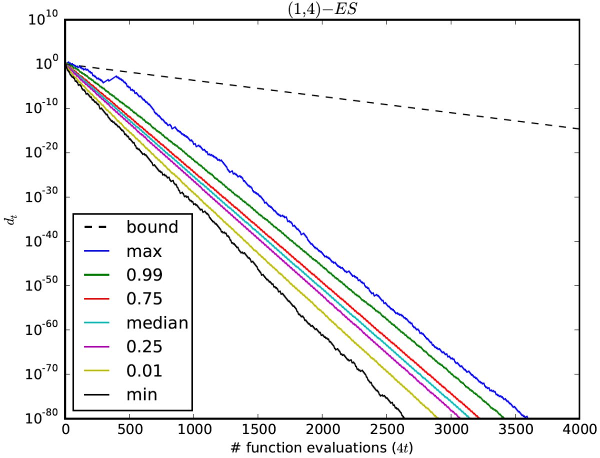
$$w^* = 1.09380 \qquad k^* = 0.29601$$

$$a^* = 0.03370 \qquad \frac{a^*}{\lambda} = 0.00842$$

Empirical quantiles of the distribution of $|x_t|$ estimated from 10001 ES runs ($\alpha_s^* = 1.19591, \quad \alpha_f^* = 0.42236$ ("close"to the optimum))



Empirical quantiles of the distribution of d_t estimated from 10001 ES runs ($\alpha_s^* = 1.19591$, $\alpha_f^* = 0.42236$ ("close"to the optimum))



Miscellaneous

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Felipe Campelo, Elizabeth F. Wanner:
Sample size calculations for the experimental comparison of multiple algorithms on multiple problem instances. CoRR abs/1908.01720 (2019)

CAISEr: Comparison of Algorithms with Iterative Sample Size Estimation

Functions for performing experimental comparisons of algorithms using adequate sample sizes for power and accuracy. Implements the methodology originally presented in Campelo and Takahashi (2019) <doi:10.1007/s10732-018-9396-7> for the comparison of two algorithms, and later generalised in Campelo and Wanner (Submitted, 2019) <arxiv:1908.01720>.

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Miscellaneous

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Application of Evolutionary Multiobjective Algorithms for Solving the Problem of Energy Dispatch in Hydroelectric Power Plants.
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