Finding pulsars with Artificial Intelligence

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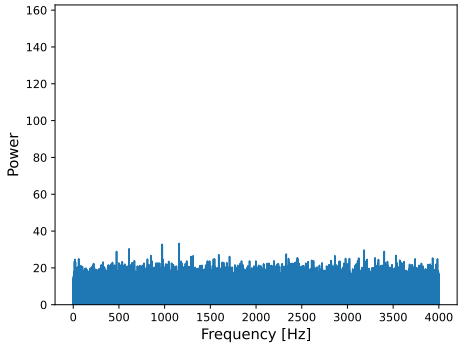
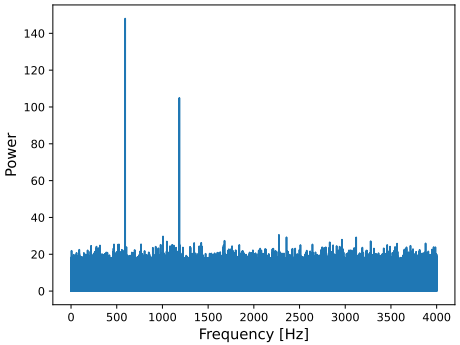
Goal

Recover a signal affected by phenomena that change its phase or period in a relatively short time, hindering their detection using traditional techniques.
A specific example is the one of **accreting pulsars**.





Finding the **orbital parameters** optimal combination to reconstruct a **corrected** time series

- For each combination of orbital parameters, the power spectral density is computed
- For each spectrum, the maximum power is determined
- Each orbital parameters combination is associated with the corresponding maximum power in the spectrum

Finding the **orbital parameters** optimal combination to reconstruct a **corrected** time series

- Exhaustive (grid) search on all combinations of orbital parameters $\Longrightarrow$ computationally **expensive**
- Targeted search on some combinations of orbital parameters $\Longrightarrow$ use of **evolutionary algorithms**

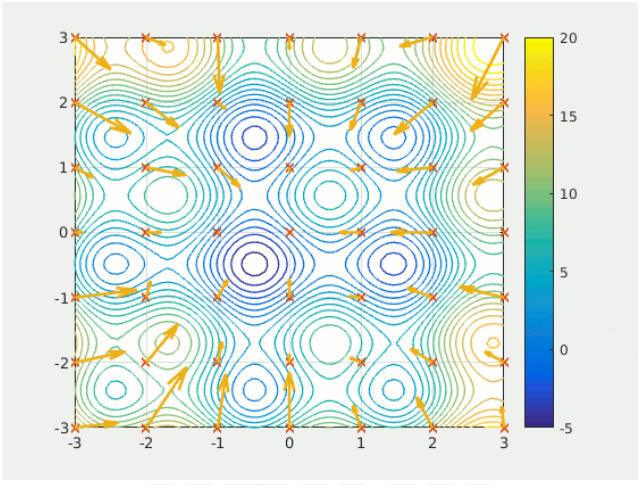
How to do a **targeted research**

- A targeted search uses **information** on the **previous** trials to **generate** subsequent orbital parameter combinations $\Longrightarrow$ generate new points in a space $\mathbb{R}^n$
- **Evolutionary algorithms** are inspired by natural processes to generate new points in space

Fundamental principles

- In nature, living beings **evolve**, or **communicate** with each other in search of food
- The living things that are **fitter for the environment** survive or are more successful
- **Simple** beings **coordinate** to achieve common goals

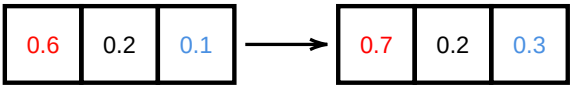
Fundamental principles



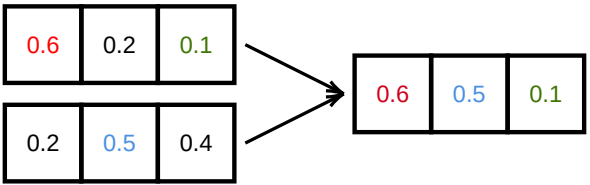
Source

- Each point in a space $\mathbb{R}^n$ is represented by a **chromosome**
- Each coordinate of a point is called **gene**
- The **best** chromosomes are more likely to survive and combine with other chromosomes

- **Mutation**: one or more genes change randomly



- **Crossover**: two chromosomes combine together



- **Selection**: given a set of chromosomes, only the best survive

Every operation is associated with a different probability.

Algorithm structure

- **Initialization**: generation of a random set of chromosomes
- **Selection**: the best chromosomes are selected, the others are eliminated
- **Evolution**: the selected chromosomes are combined with each other using crossover operations or mutate
- **Termination**

Parameters choice

- **Crossover** favors the exploitation of information from previous trials
- **Mutation** favors the exploration of space

One of the biggest difficulties is **balancing** mutation and crossover probabilities.

Results

- Compared to exhaustive search, reducing the number of iterations by a factor of at least $100 \implies$ **from 3 months to 1 day**
- Identification of sub-optimal orbital parameters on data in **X-rays** and **optical**
- Identification of **degenerate** orbital parameters in confirmed discoveries (high power, correlated with correct solutions)
- Ongoing experiments on a new source (J1544)

Future research

Searching for pulsations in large datasets is still challenging
Are there characteristics common to confirmed PULXs?

- Unsupervised algorithm $\Longrightarrow$ **agnostic** with respect to classes
- No classes known during training $\Longrightarrow$ **no overfitting**
- Discovery of **intrinsic** properties of data
- **Statistically-sound** evaluation

Gaussian Mixture Models
$\Longrightarrow$ creation of Gaussian distributions modelling data

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