A CNN adapted to time series for the classification of Supernovae

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Introduction

The cosmology
Science that studies the structure, origin and evolution of the universe

The challenge
Analyze / Detect huge amounts of data

Figure: Sky image simulation as LSST will see.

The Supernovæ
Set of phenomena resulting from the explosion of a star (various types: Ia, Ib, Ic, II ... )
Supernova

Supernova Ia: The standard candle

- A white dwarf accretes the matter of a companion star, and ends up exploding.

  **Supernova Ia video** Video credit: ESO; Downloaded from: http://www.eso.org

- Always identical explosion (intrinsic brightness)
  Luminosity observed on Earth $\Rightarrow$ deduction of distance

Supernova not Ia

- Explosion after core collapse
# Identification of celestial objects

## Identification methods

- **Spectroscopic identification**
  - Study the spectrum of the object
- **Photometric identification**
  - Identify the star using different filters

## Photometry vs. spectroscopy

- **Spectroscopy** = accurate, object must be bright, expensive
- **Photometry** = less accurate but less expensive

⇒ **LSST will provide photometric data**
Large Synoptic Survey Telescope (LSST)

LSST

- Operational from 2022
- 10-year observation project
- Will survey the visible sky twice a week
- Will provide 15 Tera of data each night
- More than 10 million supernovae will be discovered

**LSST Video** Video credit: Guillaume Doyen; Downloaded from: http://astrospace-page.blogspot.com
Light Curves

- Evolution of luminous flux over time

Figure: Example of supernova Ia simulated
Light Curves

Problems

- Irregular temporal sampling
- Variable duration
- Extremely sparse (more than 70% of 0)

Figure: Example of supernovae light curves Ia and not Ia
Outline

1. Domain presentation
2. The data
3. The CNN network
4. Results
5. Conclusion
The data

Simulated data
- Simulated data with SNANA software and corresponding to that of the Dark Energy Survey
- Simulations generated to be as realistic as possible

Some numbers
- Curves of light: 5 000
- Supernovæ la: 2 500
- Supernovæ not la: 2 500
- Sparse: More than 70% of zeros
Representation of input data

**Figure:** Representation of light curves in matrix form
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CNN Network Architecture

Figure: Convolutional neural network

The CNN is downloadable there:

https://github.com/Anzzy30/SupernovaeClassification
Plan

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5 Conclusion
Base and Hyper-parameters

Learning Base / Test Base

- **4-Fold** cross-validation
- **3 750 light curves** for the learning
- **1 250 light curves** for the test
- **Virtual increase** by crop from 40% to 80% of light curves. Reduces over-fitting and improves results

- 4500 iterations, dropout of 0.4 on the fully connected, learning rate with exponential decay from $10^{-2}$ to $5 \times 10^{-4}$, Adam optimizer, cross entropy loss, weight initialized with Xavier approach, batch of size 128 ...
- Learning with a NVIDIA GTX 1080
## Results

<table>
<thead>
<tr>
<th>Model</th>
<th>Training set</th>
<th>AUC</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNN</td>
<td>3750</td>
<td>0.984</td>
<td>94.6</td>
</tr>
<tr>
<td>SALT2</td>
<td>3750</td>
<td>0.979</td>
<td>92.3</td>
</tr>
<tr>
<td>FATS</td>
<td>3750</td>
<td>0.964</td>
<td>90.1</td>
</tr>
<tr>
<td>Siamese</td>
<td>3750</td>
<td>0.963</td>
<td>93.0</td>
</tr>
</tbody>
</table>

Accuracy = \[
\frac{TP + TN}{TP + TN + FP + FN}
\]

[Lochner et al. 2016] SALT2: Boosted decision tree (BDT) using SALT2 features (Spectral Adaptive Light curve Template 2)

[Nun et al. 2015] FATS: Boosted decision tree (BDT) using FATS (Feature Analysis for Time Series)
Analysis

- Better than the state-of-the-art ("features + classifier")
- Deep network performance can easily be improved
- Increasing the number of examples (not shown here) improves the results of deep learning
- Results of the RNN slightly lower than the CNN (not shown here)
Improvements

- Virtual increase by noise addition
- Improvement of performance by using Ensemble, transfer learning, multi-class, use of redshift
- Extension: Better manage sparsity
- Extension: Manage the low number of samples
- Extension: Manage the mismatch between celestial objects near and far
- Extension: Manage the cadence mismatch (sparsity)

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## Conclusion and perspectives

### Objectives
- Binary classification of supernovae Ia and not Ia
- Manage locks due to LSST data

### Contributions
- Two state-of-the-art networks
- CNN or triplet loss approaches are possible

### Perspectives
- Kaggle
The Large Synoptic Survey Telescope (LSST) is about to revolutionize the field, discovering 10 to 100 times more astronomical sources that vary in the night sky than we’ve ever known. The Photometric LSST Astronomical Time-Series Classification Challenge (PLAsTiCC) asks Kagglers to help prepare to classify the data from this new survey.

- $25,000 in total prizes
- Timeline:
  - September 28, 2018 - Launch
  - December 10, 2018 - Entry deadline and Team Merger deadline
  - December 17, 2018 - Final submission deadline.
  - January 15, 2019 - LSST Workshop entry deadline.
  - February 15, 2019 - LSST Workshop announcement.

[Link to competition](https://www.kaggle.com/c/PLAsTiCC-2018)