Machine learning techniques to classify transients using LSST: a proof of concept using MeerLICHT

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Outline

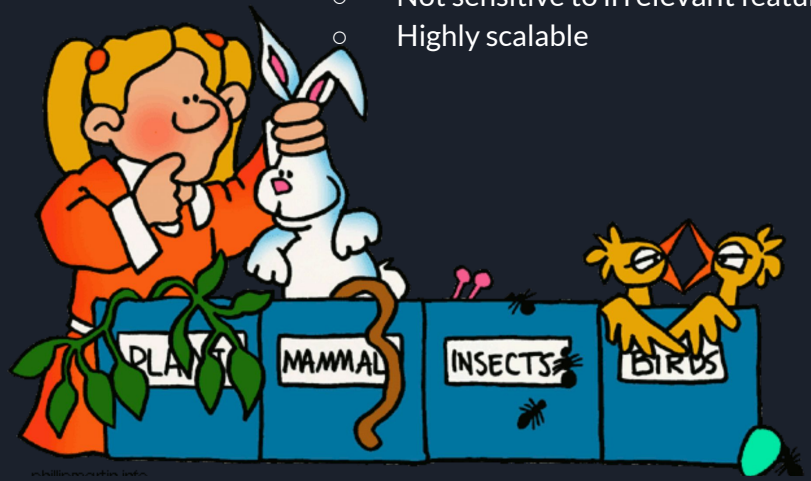
- Assorted ML classifiers
  - Naive Bayes
  - Support Vector Machines
  - Random Forests
  - Neural Networks
- LSST / VRST
  - Design
  - Data Reduction/Analysis
  - Expected results
- MeerLICHT
  - Design
  - Data Reduction/Analysis
- Convolutional Neural Network
  - Goals
  - Current design
  - Eventual design
  - Preliminary results
- Conclusion

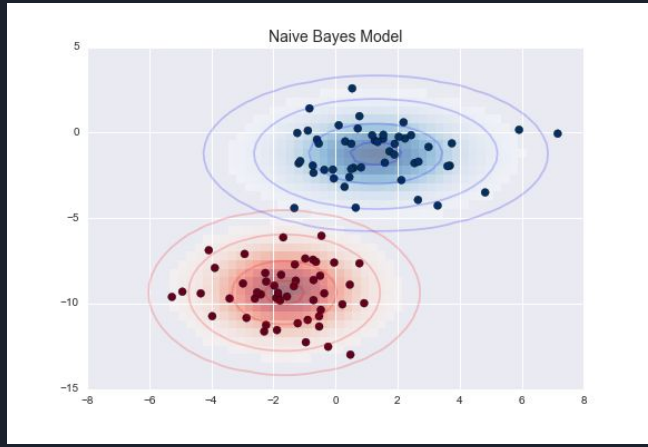
Machine learning classifiers

Naive Bayes

- Advantages
  - Independent features
  - 1D kernel density estimation
  - Fast training/classification
  - Suited for high dimensionality
  - Not sensitive to irrelevant features
  - Highly scalable

- Disadvantages
  - Assumes independency of all variables
  - cannot learn interactions between variables
  - Imbalanced classes equals skewed results
  - Data scarcity



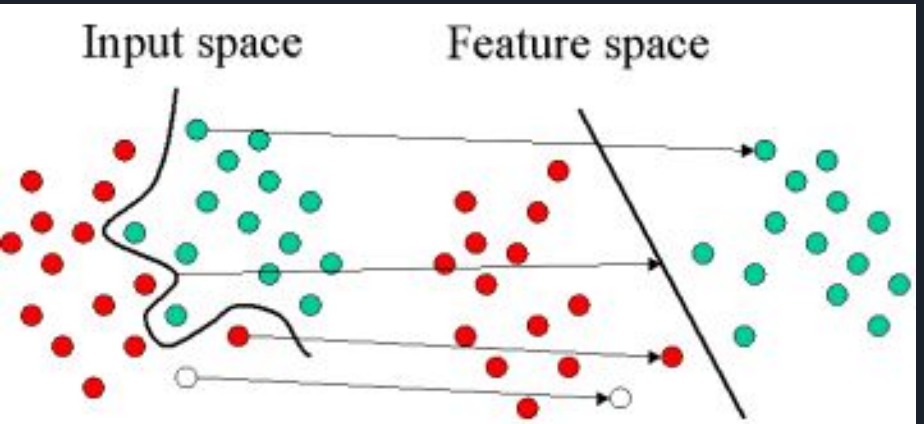


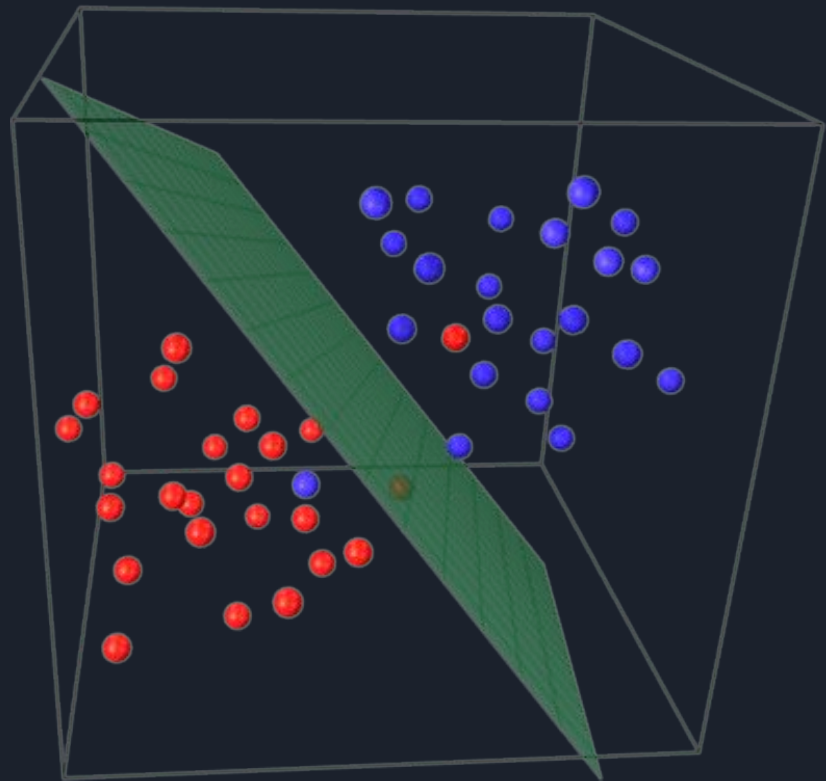
Python Data Science Handbook

Machine learning classifiers

Support Vector Machines

- Non-probabilistic classifier
- Optimal hyperplane
- Separable in higher dimensions
- Unique solutions
- Difficult to represent class scores



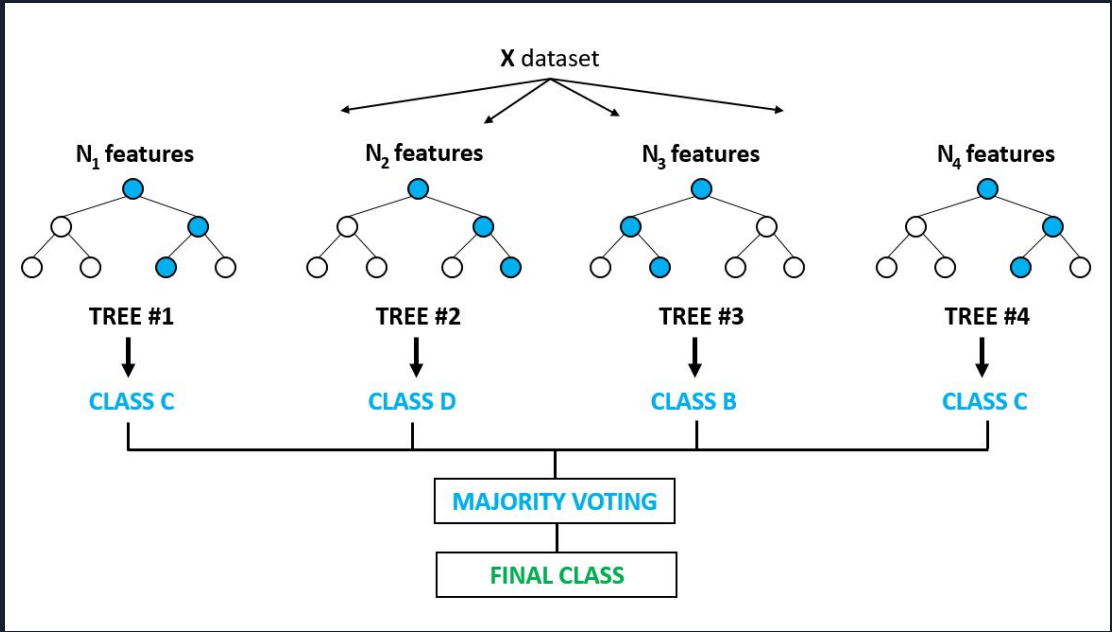


Machine learning classifiers

Random Forests

- Decision trees
  - Binary decisions
  - Random features
  - Stop: single class

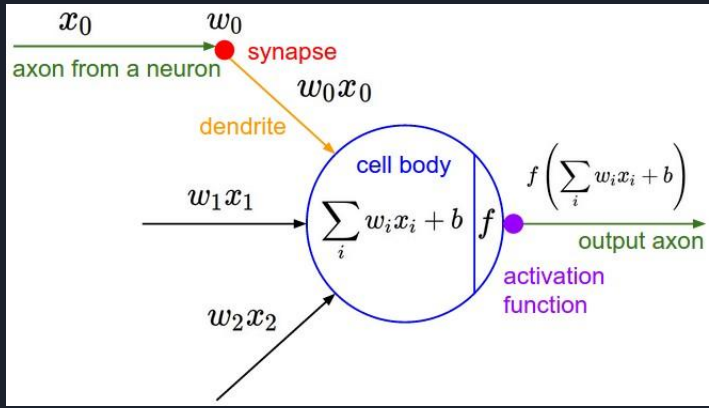
- Random Forests
  - Bagging classifier
  - Multiple trees
  - Increase stats
  - Highly scalable

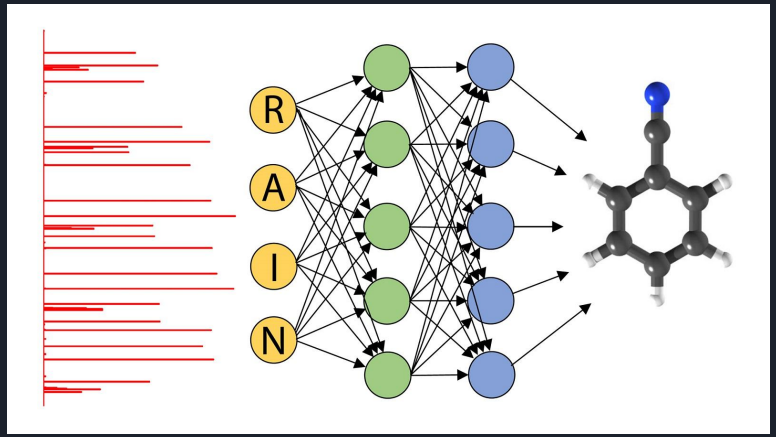


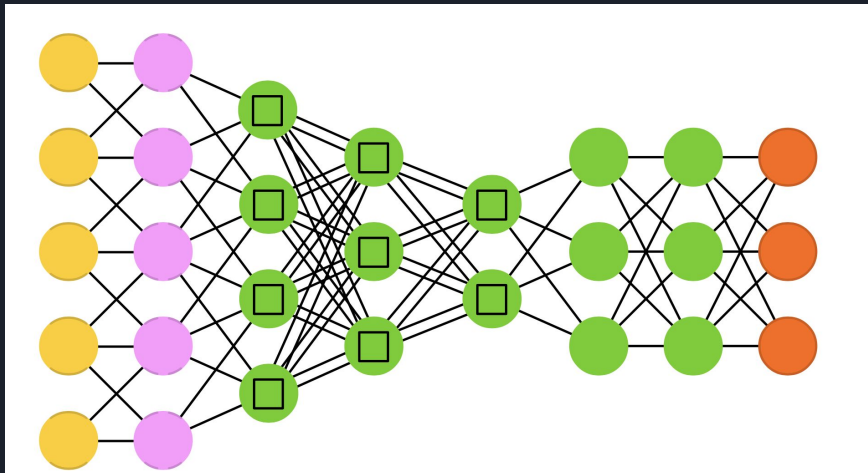
Machine learning classifiers

Neural Networks

- Inspiration from brain
- Very good at pattern recognition
- Large number of inputs
- High accuracy







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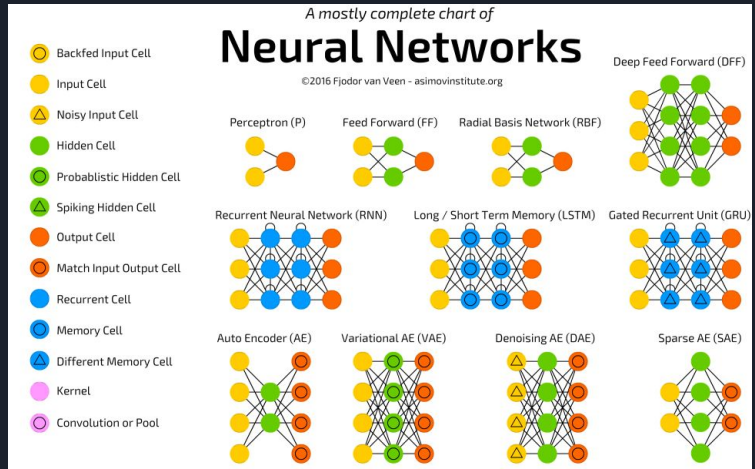
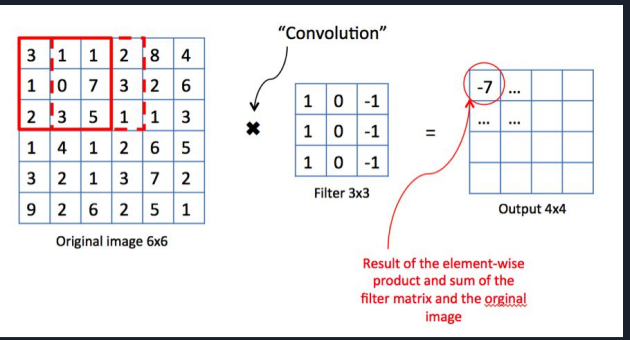
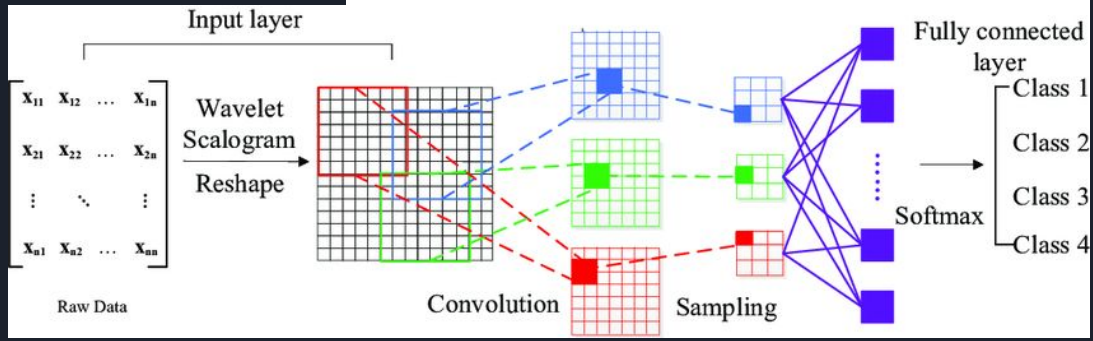






Wang et al. 2018

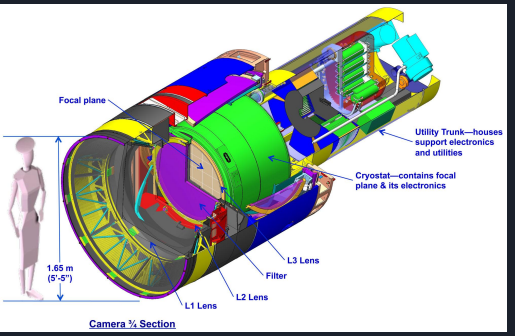
Large Synoptic Survey Telescope

Large Synoptic Survey Telescope (LSST)

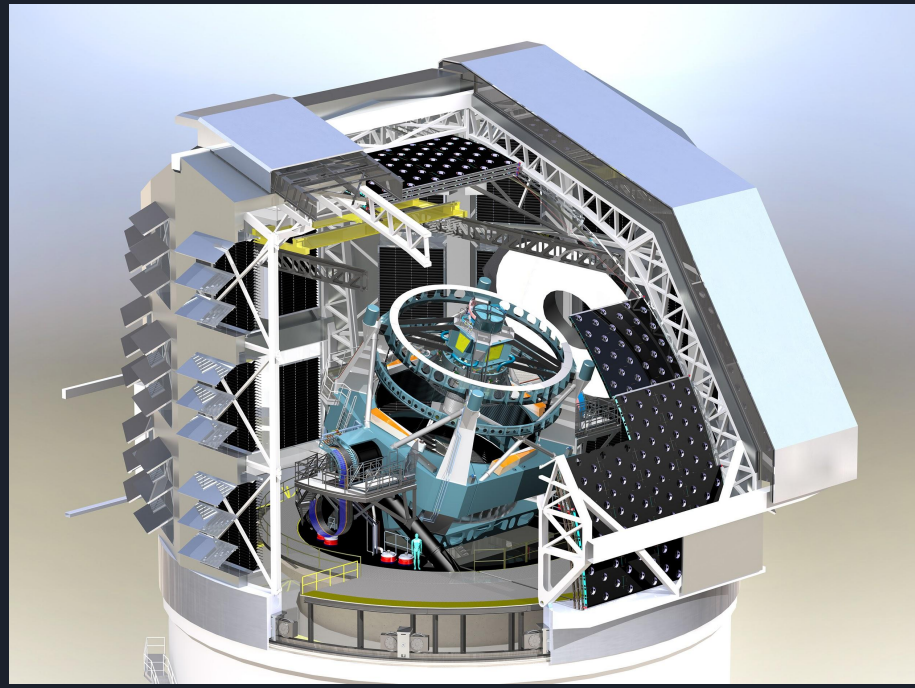
Vera Rubin Survey Telescope (VRST)

Design

- Cerro Pachón, Chile
- 8.4-m mirror
- 3 mirror design
- FoV: 9.6 deg^2
- 3.2 Gigapixel CCD
- *ugrizy* filters



LSST Gallery



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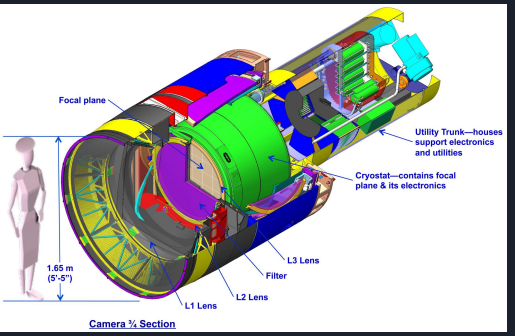
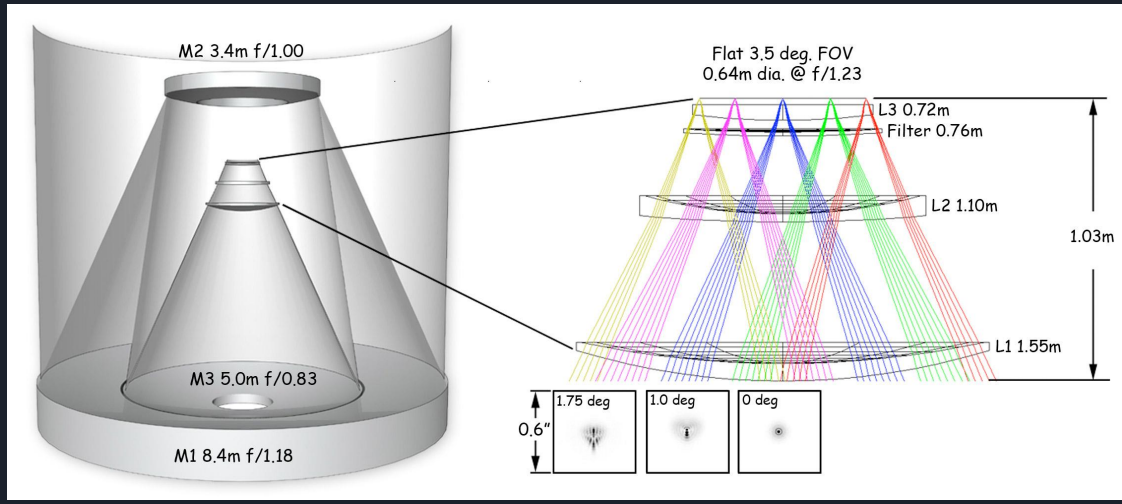




LSST Gallery

LSST Gallery

Large Synoptic Survey Telescope (LSST)
Reduction/Analysis

Prompt

- DIA
- Source detection
- Alerts
- Public

Daily

- 30 day LC
- Moving object

Data Release

- Yearly data release
- DIA rerun on all data
- Stacked CoAdds created
- Source detection, association and characterization
- Forced photometry for all objects

Large Synoptic Survey Telescope (LSST)
Expected Results

- 18000 deg^2 survey area
- Single-visit exposure: 30s (2x15s)
- Single-visit depth : 25.0 (g)

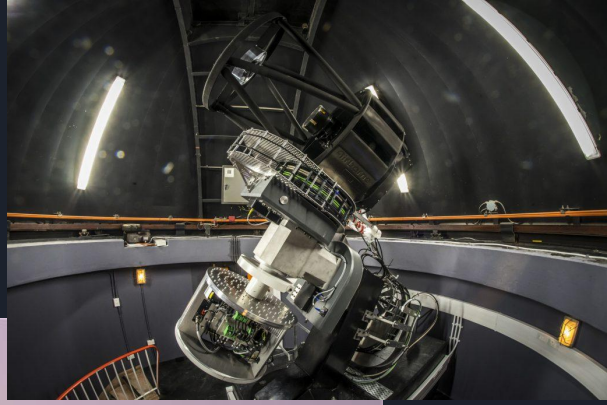
- 37 Billion stars and Galaxies
- 10 million alerts/night
- 15 Terabytes/night

LSST Gallery

MeerLICHT

MeerLICHT

A slave to MeerKAT



Design

- Located in Sutherland, South Africa
- Real-time optical view of radio sky
- 0.65-m Robotic telescope
- FoV: 2.7 deg^2 (same as MeerKAT)
- 100 Megapixel, singe CCD
- Filters: *ugriz* + q
- Cadence: 1 min (q, *u*, q, *g*, q, *r*, q, *i*, q, *z*, ...)

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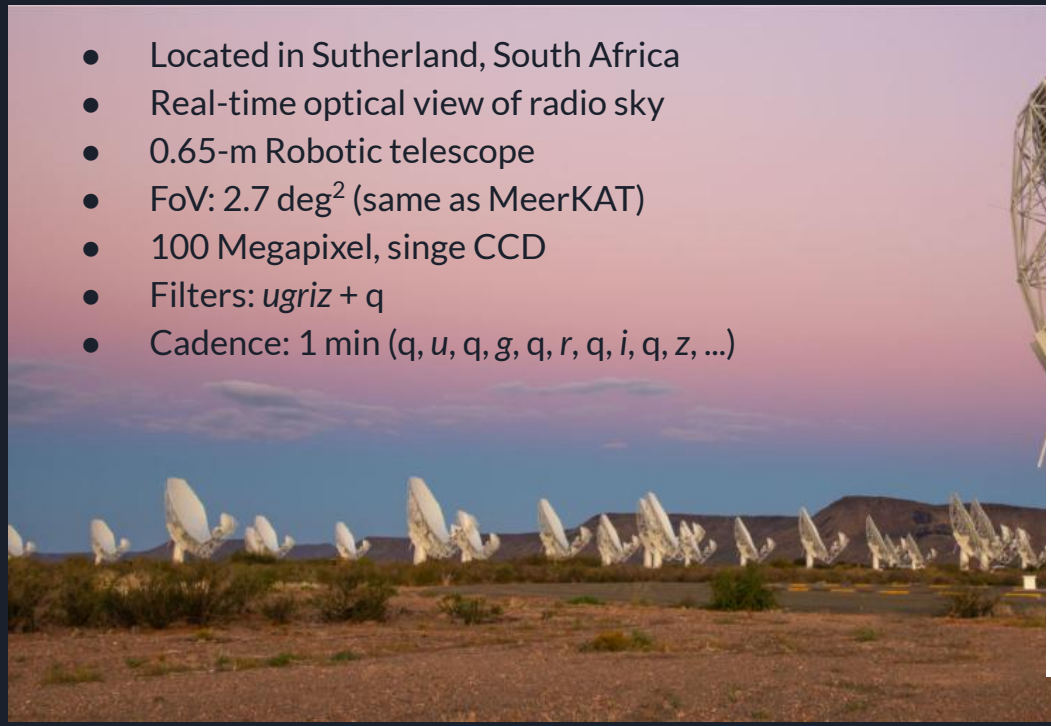
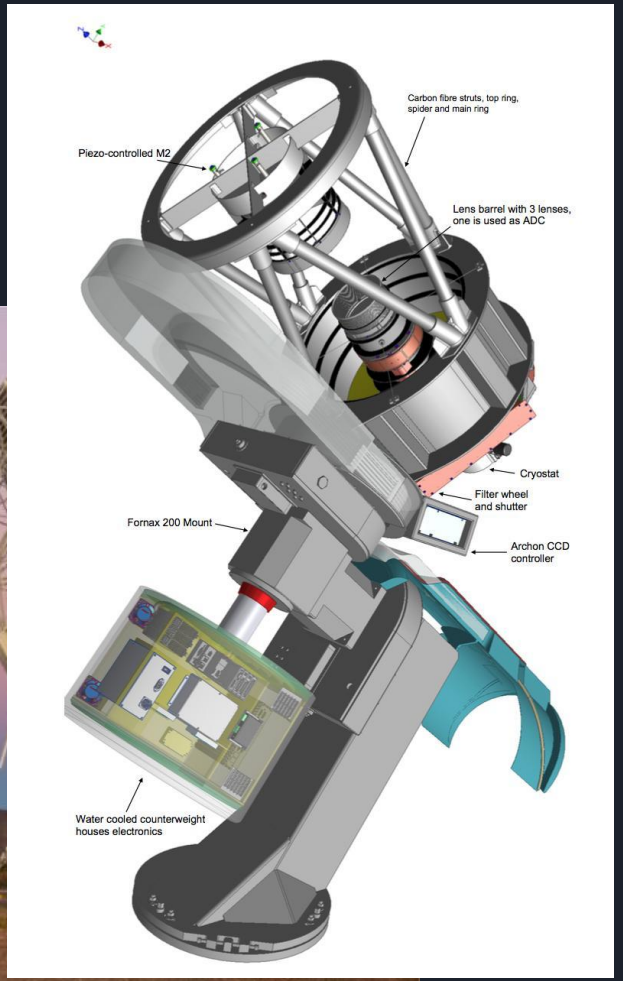




Bloemen et al 2016

MeerLICHT

A slave to MeerKAT

Data Analysis

- Day mode
  - Master calibration files
  - Reduce all data
- Night mode
  - Transient detection
  - Real-time alerts
  - VOEvents

Data Analysis

- DIA alerts
- ZOGY (Zackey et al 2016)
  - Performs image subtraction
  - Significance image
  - PSF photometry image
- Optimal photometry
  - Speed of aperture photometry
  - Accuracy of PSF photometry

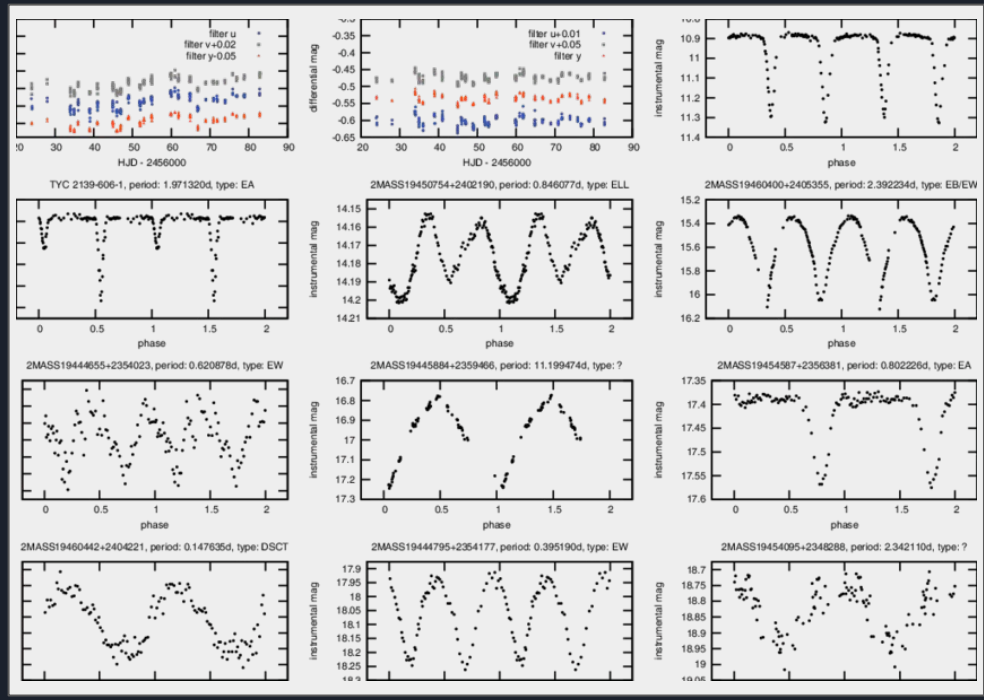

MeerLICHT
Small Magellanic Cloud
u, *g*, *r*, *i*, *z* Composite

CNN to detect novel transients

CNN to detect novel transients

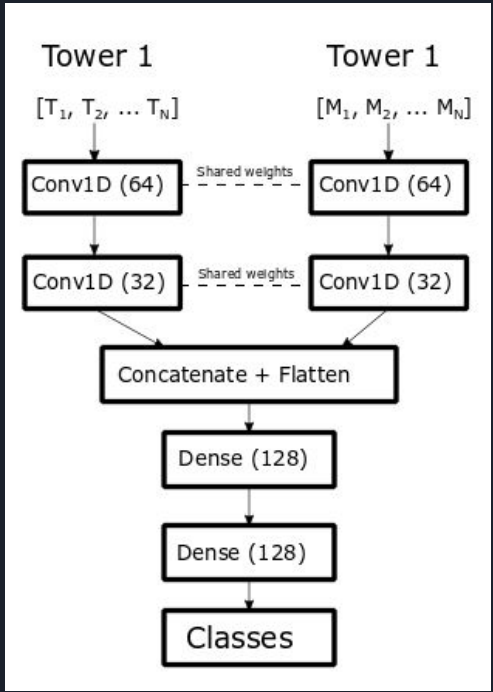
Goals

- Step 1: Classify
  - Variables
  - Transients
- Step 2: Predict
  - Next observation
  - Next few observations
- Step 3: Construct
  - Autoencode features
  - Reconstruct simple LC
- Step 4: Alert
  - Compare prediction to encoded LC
  - Alert for significant deviation

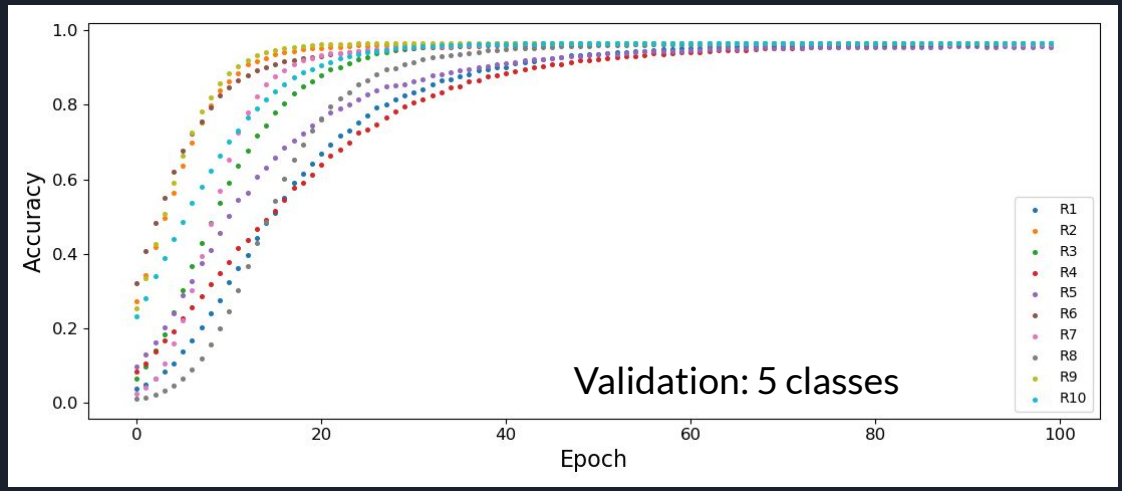


CNN to detect novel transients

Current Design + Initial Results



- Optimizer: Stochastic Gradient Descent
- Learning rate: 0.005
- Activation: ReLu



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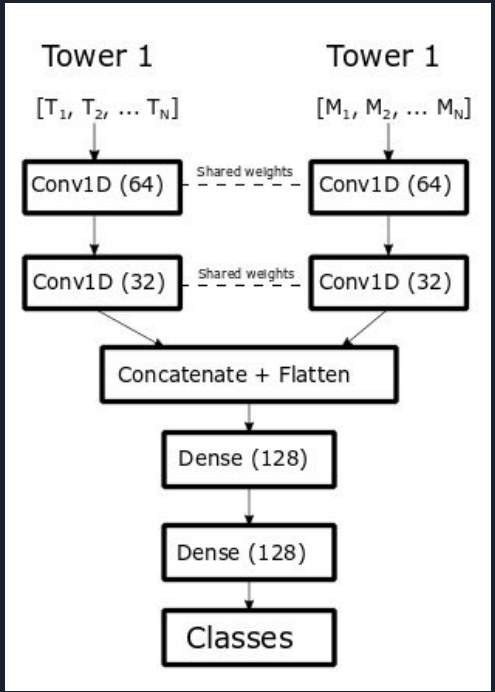

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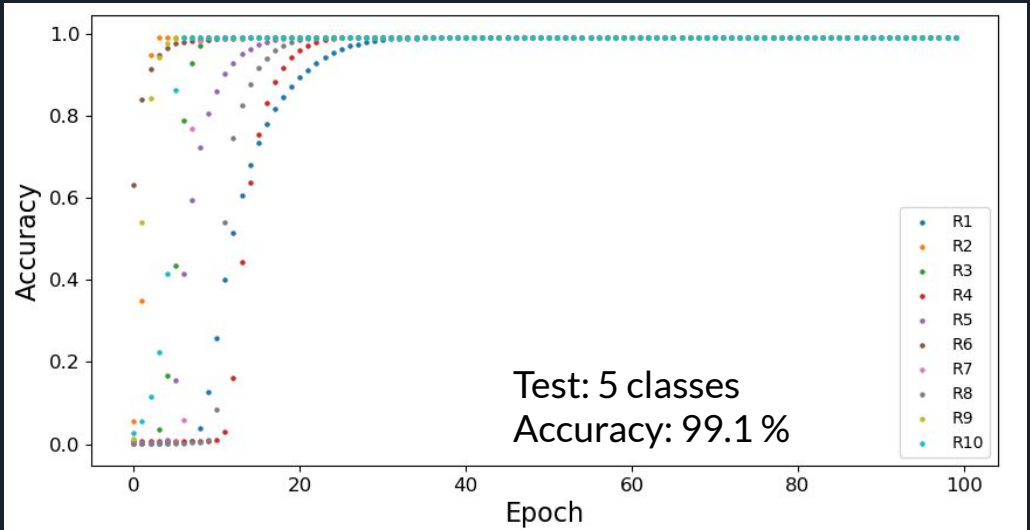
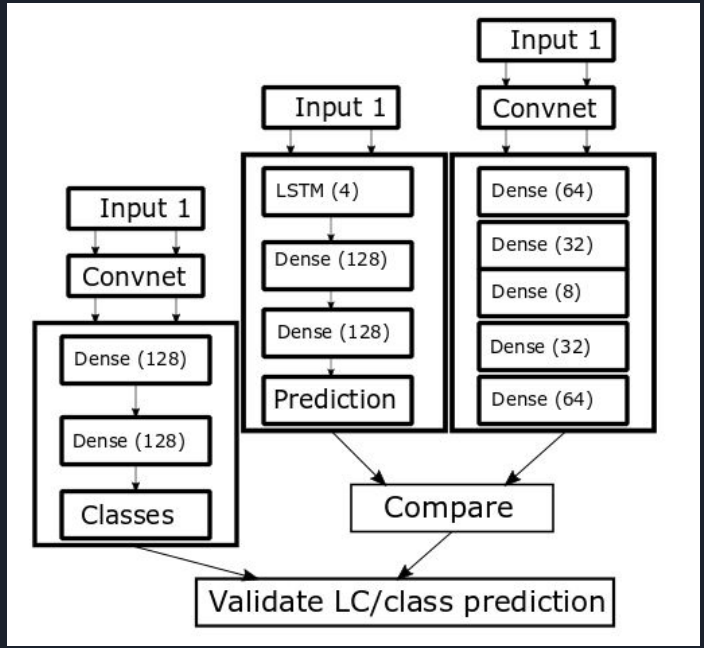


CNN to detect interesting transients
Future Design

- Classifier
  - Newly detected sources
- Autoencoder
  - Reconstruct general LC for class
- LSTM Sequence prediction
  - Predict next points in sequence
- Compare LSTM and Autoencoder
  - Is source variable
  - False alarm



Conclusion

- LSST
  - Terabytes of data/night
  - Millions of alerts
  - Operation start: 2022
- MeerLICHT
  - Slaved to MeerKAT
  - Simultaneous radio + optical
  - Ideal to test ML techniques
- Simple CNN
  - Good accuracy
  - Random training data
  - Unstable learning rate
- Future
  - CNN capable of predictions
  - General LC
  - Classify new sources

Thank You