Tiana_Athrieldhuppenkothen

Classifying Black Hole States – Lessons Learned in Machine Learning–

Daniela Huppenkothen DIRAC Institute, UW Seattle



How do black holes accrete matter?

jet physics + particle acceleration

plasma physics + magnetic fields

ILLUSTRATION



General Relativity

What is the long-term evolution of black hole X-ray binaries?

GRS 1915+105







Belloni et al, 2000, Klein-Wolt et al, 2002, Hannikainen et al, 2004

(s)



Belloni et al, 2000, Klein-Wolt et al, 2002, Hannikainen et al, 2004

"Machine Learning, a subfield of computer science, involves the development of mathematical algorithms that discover knowledge from specific data sets, and then "learn" from the data in an iterative fashion that allows predictions to be made"

– NYAS Machine Learning Symposium

+ very flexible + works on large data sets

— sometimes hard to interpret — strongly input-dependent

+ excellent at prediction problems

— often not designed to do inference



Belloni et al, 2000, Klein-Wolt et al, 2002, Hannikainen et al, 2004

(s)

Lesson 1: data characteristics are important!

GRS 1915+105

• $\sim 10,000$ light curves • "ground truth" classifications supplied by humans heavily imbalanced data set •



Lesson 2: Feature Engineering is hard!



Belloni et al, 2000, Klein-Wolt et al, 2002, Hannikainen et al, 2004

(s)

Feature Engineering

- mean/variance/skew of time series •
- •
- maximum power in PSD
- power colours (Heil et al, 2014) •
- PCA decomposition of PSD

autoregressive model of time series hardness ratio mean/variance/covariance

Lesson 3: sometimes fancy methods doesn't help!

Machine Learning

 logistic regression cross-validation • 92.5% accuracy on test set

https://github.com/dhuppenkothen/BlackHoleML



use human classification as "ground truth"



Huppenkothen et al, 2017

Lesson 4: physical interpretation requires probabilities



Distribution of states evolves over 16 years!

Huppenkothen et al, 2017

							m	•,•	٦ <i>.</i> ۲						
	[0.005	0.100	0.000	0.00-		ansitio	n Mat	o coo	0.000	0.000	0.000	0.022	0.000
	α	0.478	0.225	0.130	0.000	0.007	0.007	0.014	0.000	0.022	0.036	0.000	0.022	0.022	0.036
	β	0.013	0.729	0.090	0.016	0.002	0.007	0.011	0.004	0.022	0.021	0.003	0.016	0.021	0.044
	χ	0.008	0.030	0.859	0.012	0.002	0.007	0.009	0.002	0.007	0.016	0.002	0.016	0.014	0.016
	δ	0.000	0.037	0.099	0.737	0.002	0.023	0.009	0.007	0.012	0.018	0.002	0.025	0.021	0.007
	η	0.014	0.014	0.068	0.000	0.753	0.000	0.014	0.014	0.000	0.027	0.014	0.014	0.055	0.014
	γ	0.000	0.040	0.092	0.026	0.000	0.736	0.015	0.004	0.026	0.007	0.007	0.011	0.022	0.015
state	κ	0.006	0.038	0.076	0.009	0.000	0.006	0.700	0.035	0.067	0.009	0.003	0.012	0.015	0.026
Initial	λ	0.010	0.050	0.109	0.040	0.000	0.020	0.109	0.554	0.059	0.000	0.030	0.010	0.000	0.010
	μ	0.005	0.108	0.073	0.011	0.000	0.022	0.024	0.030	0.667	0.005	0.000	0.019	0.024	0.013
	ν	0.033	0.052	0.225	0.016	0.003	0.007	0.016	0.003	0.010	0.562	0.007	0.013	0.020	0.033
	ω	0.010	0.020	0.099	0.030	0.020	0.020	0.030	0.020	0.000	0.010	0.663	0.059	0.020	0.000
	ϕ	0.003	0.035	0.103	0.012	0.001	0.001	0.007	0.001	0.009	0.003	0.003	0.795	0.018	0.009
	ρ	0.003	0.054	0.075	0.010	0.003	0.008	0.013	0.002	0.020	0.013	0.008	0.011	0.759	0.020
	θ	0.006	0.088	0.076	0.010	0.001	0.007	0.003	0.000	0.006	0.016	0.007	0.017	0.014	0.748
	l	α	β	χ	δ	η	γ	κ Final	λ	μ	ν	ω	ϕ	ρ	θ
								1,11191	state						

Evolution may follow patterns

Huppenkothen et al, 2017

0.6

0.3

0.2



Evolution may follow patterns

Huppenkothen et al, 2017

Lesson 5: Human-based classifications are only accurate to ~90% (and may include biases)

Future: Combine machine learning with Bayesian inference!

Hidden Markov Models*



http://ngoix.github.io/cyg-x1/index.html

*with V. Grinberg, A. Müller and N. Goix

Use methods from computational chemistry!

Conclusions

- astrophysical objects
- is important)
- -1915 + 105

time series are an important tool to study physical processes in black holes and other

machine learning can be an excellent tool to uncover structure (but interpretability

using logistic regression, we can uncover the long-term state evolution of GRS