Forex trend prediction

with rough sets and machine learning

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Outline

Interact at

https://tinyurl.com/tellsatuelisa

Heiken Ashi candles (HA)

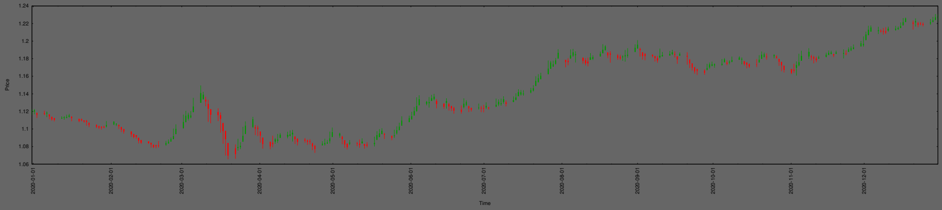
HA closing (HAC) is the *average* of `OCLH` for t

HA opening t (HAO) is the *average* of HAO and HAC for $t-1$

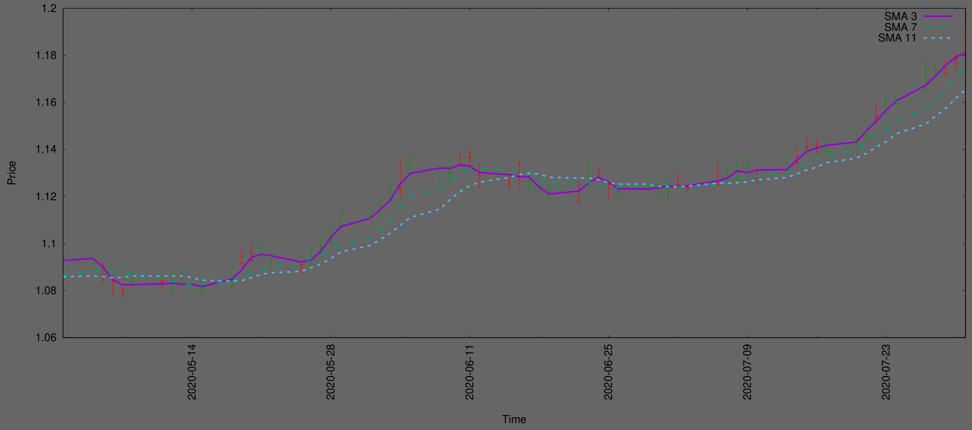
HA high (HAH) is the *maximum* of HAO, HAC, and `H` for t

HA low (HAL) is the *minimum* of HAO, HAC, and the `L` for t

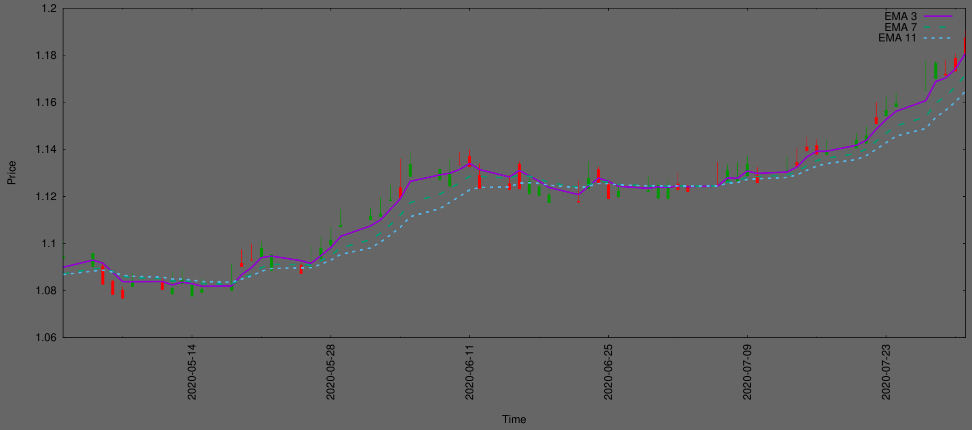
Base case $t = 0$ just uses `OCLH` (avg/avg/max/min)



Rolling *average*: SMA



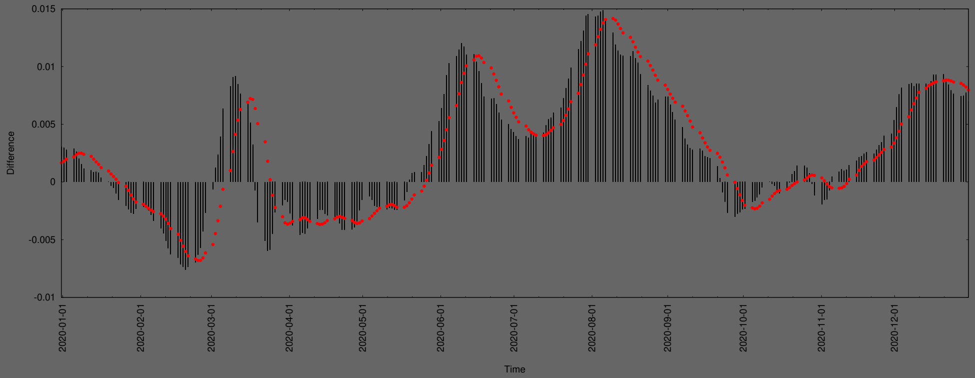
Prioritize *recent data*: EMA



Moving average convergence-divergence

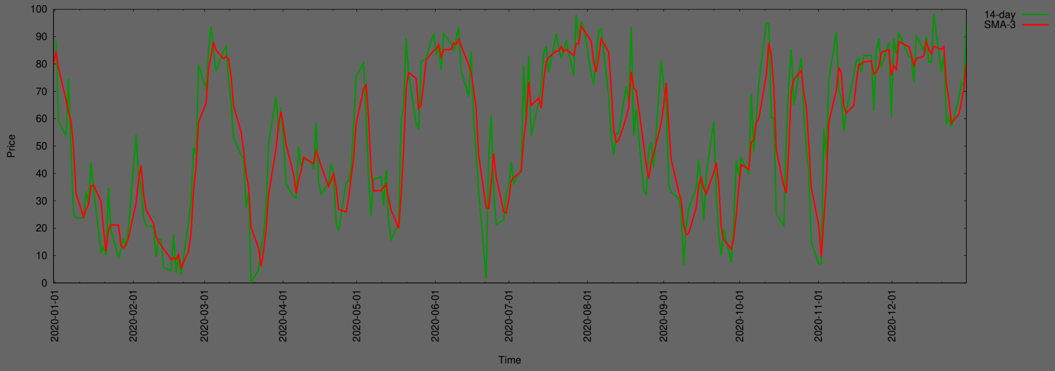
Two MA: a *fast* one and a *slow* one

d = how many differences between the fast and the slow MA to compute



Stochastic oscillator (SO)

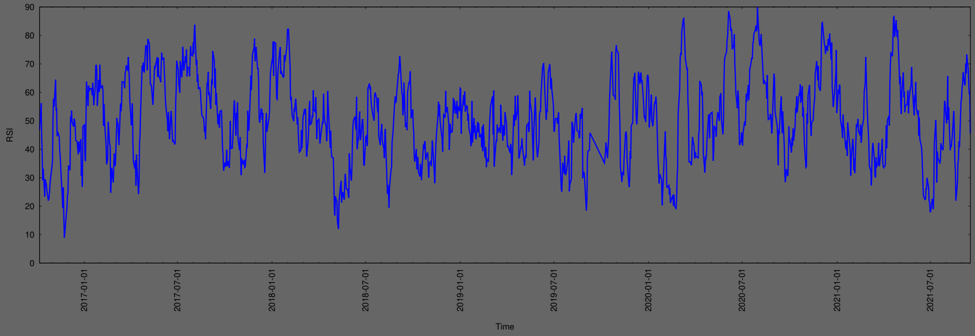
$$s_t = \frac{\text{closing}_t - \text{lowest}_{[t-\ell,t]}}{\text{highest}_{[t-\ell,t]} - \text{lowest}_{[t-\ell,t]}}$$



Relative strength index (RSI)

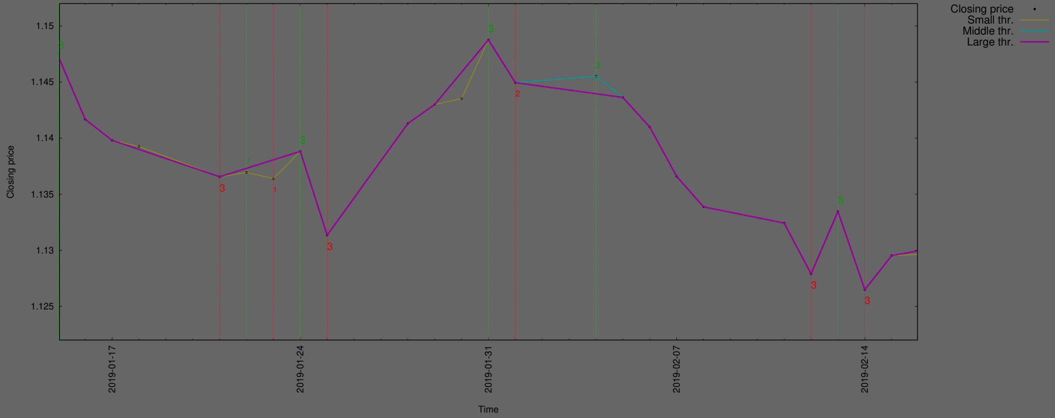
Initial: $\mathrm{RSI}_\ell = 100 - 100 \,/\, (1 + \frac{\mathrm{gain}_\mu}{\mathrm{loss}_\mu})$

For $t > \ell$: $\mathrm{RSI}_t = 100 - 100 \,/\, (1 + \frac{(\ell-1)\times\mathrm{gain}_\mu + \mathrm{gain}_t}{(\ell-1)\times\mathrm{loss}_\mu + \mathrm{loss}_t})$



Zig-zag semaphore

t at which the price reverses (direction = sign, magnitude = kind)



Forex prediction

Traditional approaches for forecasting have fallen short [15] whereas non-linear models have been found adequate [6].

The research on the forex dates back to the work of Meese and Rose [9] who discarded the use of known forecasting methods for this particular market in 1991.

With ML, however, it has been a whole new ballgame.

An extract of related work

Work	Technique	Aspect	Pairs	Features
Baasher and Fakhr [3]	SVM+	trend	4	indicators
Adariani [1]	TTR	profit	10	indicators
Vyklyuk et al. [16]	NN	rate	1	price
Nayab et al. [11]	DT+RS	rate	10	indicators
Lee et al. [7]	HMM	trend	1	manual
Zarrabi et al. [18]	TTR	profit	6	indicators
Carapučo et al. [4]	NN	profit	1	price
Munkhdalai et al. [10]	DL	rate	6	indicators
Ni et al. [12]	NN	rate	9	price
Svoboda and Sponerová [14]	TTR	rate	1	indicators
Dautel et al. [5]	DL	change	4	price
Adegboye and Kampouridis [2]	ML	reversal	20	price
Yildirim et al. [17]	DL	profit	1	indicators
Present work†	RS+ML	trend	15	indicators

† R2 sent on January 7th for Springer's *Computational Economics* (with Fernando and Chris)

Classification and rough sets

A *classifier* is a method that assigns to each input a *label* from a set of k predefined class labels.

Two *alternatives* x_1 and x_2 are defined to be *indiscernible* in terms of a subset of *attributes* A if each attribute $a \in A$ assigns the same value to them,

$$\forall a \in A : a(x_1) = a(x_2)$$

If only the attributes in A are considered, x_1 and x_2 are *equivalent* [13]

Equivalence class

$[x]_A =$ the subset of objects that are indiscernible in terms of A

Reduct R of A = a minimal subset of A that conserves equivalence

The intersection of all its reducts is the *core* of A

Picking the attributes that *distinguish* between equivalence classes
$\approx$
Approximating an equivalence class as a subset of inputs with the same label

Approximation

Let T be a subset of *targets* to characterize in terms of A

Unless T is an equivalence class under A, it can only by approximated in terms of A

Lower approximation $\underline{T}_A = \{x \mid [x]_A \subseteq T\}$
Upper approximation $\overline{T}_A = \{x \mid [x]_A \cap T \neq \emptyset\}$
Precision of approx. $\alpha(T, A) = |\underline{T}_A| / |\overline{T}_A|$

$a \in A$ is *redundant* if $\underline{T}_A = \underline{T}_{A \setminus \{a\}}$

Fuzzy rough sets

Whether or not an element belongs to a rough set is **not** a binary decision

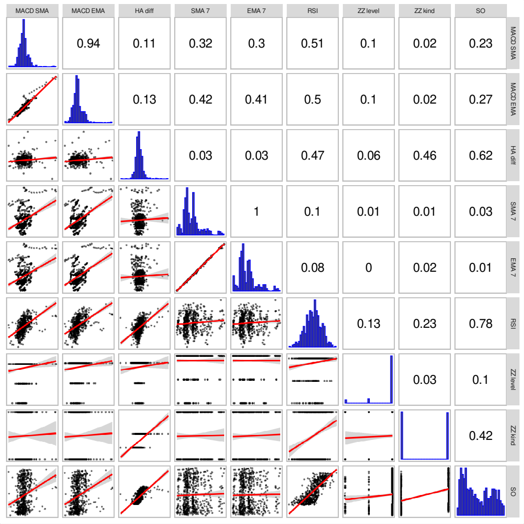
Instead a (discrete or continuous) *degree of belonging* is employed

Python library: `fuzzy-rough-learn` [8]

https://pypi.org/project/fuzzy-rough-learn/

We use *Fuzzy Rough Neighbourhood Consensus* (FRONEC) labelling

- lower approximation (Q^1)
- *Hamming* distance (R^1)
- $k = 10$ neighbors


MACD SMA
MACD EMA
HA diff
SMA 7
EMA 7
RSI
ZZ level
ZZ kind
SO
0.94 0.11 0.32 0.3 0.51 0.1 0.02 0.23
0.13 0.42 0.41 0.5 0.1 0.02 0.27
0.03 0.03 0.47 0.06 0.46 0.62
1 0.1 0.01 0.01 0.03
0.08 0 0.02 0.01
0.13 0.23 0.78
0.03 0.1
0.42

USDMXN

Feature extraction

We compute the indicators and then discretize them:

SMA	P+ (1) or - (0) difference to price
EMA	same as SMA
HA	*rising* (1) or *falling* (0)
ZZ	level (1/2/3) & kind (0/1); most recent
SO	above (1) or below (0) SMA-14
RSI	5-level discretization of the index
MACD	sign (0/1)

Several windows for SMA and EMA (3, 5, 7, 9, 11)
Two MACD (F12/S26/D9): one using SMA and another with EMA

Horizons and thresholds

Forecast horizons **H**: how many days in the future, counting from the date on which the indicators are *observed*, the forecast is placed

Change thresholds **T**: how many percent the price needs to differ between the day on which the indicators are observed and the day for which the forecast is made for that level change to be considered present

Given **H** and **T** we compute two binary values based on the price graph:

- 1 if the change exceeds **T**, 0 if it does not
- 1 if the change is an increase, 0 if it is a decrease

Combinations

$\mathbf{H} \in \{1, 2, 3, 4, 5, 10, 15\}$

$\mathbf{T} \in T_s \cup T_m \cup T_\ell$

$$\begin{aligned} \text{small} \quad T_s &= \{0.01, 0.02, 0.03, 0.04, 0.05\} \\ \text{medium} \quad T_m &= \{0.1, 0.2, 0.3, 0.4, 0.5\} \\ \text{large} \quad T_\ell &= \{1.0, 1.5, 2.0, 2.5, 3.0\} \end{aligned}$$

Class labels

The pairs **HT** are then mapped to integer labels as follows:

$\uparrow = 2$	for the $(1, 1)$ pairs that indicate an **increase** above the threshold
$\approx = 1$	for the $(0, 1)$ and $(0, 0)$ pairs that indicate **no change** big enough
$\downarrow = 0$	for the $(1, 0)$ pairs that indicate a **decrease** above the threshold

Features and labels

Date	SMA					EMA					HA	ZZ-S		SO	RSI	MACD		Forecast
	3	5	7	14	21	3	5	7	14	21		Lvl	Kind			SMA	EMA	
2016-12-26	1	1	1	1	0	1	1	0	0	0	1	3	1	0	2	0	0	1
2016-12-28	1	1	1	1	1	1	1	1	0	0	0	2	1	0	1	0	0	2
2016-12-29	0	0	0	0	0	0	0	0	0	0	0	3	0	1	1	0	0	2
2016-12-30	1	1	1	1	1	1	1	1	1	1	1	3	1	0	2	0	0	0
2017-01-04	0	0	0	0	0	0	0	0	0	0	0	3	0	1	1	0	0	2
2017-01-06	1	1	1	1	1	1	1	1	1	1	1	3	1	0	3	0	0	1
2017-01-09	0	1	1	1	1	0	1	1	1	1	0	3	0	1	2	0	0	1
2017-01-10	1	1	1	1	1	1	1	1	1	1	1	3	1	0	3	0	0	1
2017-01-11	0	0	1	1	1	0	1	1	1	1	0	3	0	1	3	0	0	1
2017-01-16	1	1	1	1	1	1	1	1	1	1	1	3	1	0	3	0	0	1
2017-01-17	0	0	0	1	1	0	1	1	1	1	1	3	0	1	2	1	0	1
2017-01-18	1	1	1	1	1	1	1	1	1	1	1	3	1	0	3	1	0	1
2017-01-19	0	0	0	1	1	0	0	1	1	1	0	3	0	1	3	1	0	1
2017-01-24	1	1	1	1	1	1	1	1	1	1	1	3	1	0	3	1	1	1
2017-01-25	0	1	1	1	1	1	1	1	1	1	1	3	0	1	3	1	1	1

An extract of the data for a two-day horizon and a one-percent threshold, AUD-USD

Feature selection

- redundancy with another feature
- avoid over-fitting
- reduce time of the training

Fuzzy Rough Feature Selection (FRFS) from `fuzzy-rough-learn` [8]

We rewrote some of it to gain access to the list of features it selects to analyze the frequencies

Model building

1. Check how many data points we have per class
2. If one is a clear minority (< 30), we discard it
3. For each replica
    - Balance the classes that are adequately present
    - Split the data into testing and training
    - Use a *sample* of the **training** data for feature selection
    - Filter out the un-selected features
    - Train the classifier model
    - Predict and de-fuzz the labels (check for blanks)
    - Compute the F score

Classifier performance

Confusion matrix: counters for *predicted* vs. *expected* labels

Precision P	ratio of *true* positives from **all** positives
Recall R	ratio of *true* positives to the sum of TP & FN
F score	$2(P \times R)/(P + R)$, but weighted by class support

Experimental setup

The indicator computations are *deterministic* $\rightarrow$
Characterize just once per currency pair

Splitting of the input data into training and test sets is *probabilistic* $\rightarrow$
Several replicas per H/T combination

OS	Ubuntu 20.04.1
DS & ML	Python 3 and Bash
Dataviz	R and Gnuplot
Data	https://finance.yahoo.com/ (15 pairs, 5 years)
Repo	https://github.com/satuelisa/Forex

Steps

1. Obtain *price data*; calculate *indicators*; extract *features*
2. Choose **H** and **T**; compute class labels
3. Check if at least two classes are adequately present; terminate if not
4. Split the the data (70%, 30%)
5. Check if the classes are present in both sides of the split
6. If not, try again a maximum of 10 times; terminate if unsuccessful
7. Perform *feature selection* (50 of the 70%)
8. Construct a *classifier* (all of the 70%)
9. *Predict* the test data (30%); compute the *F-score*
10. Iterate from 4 until the *replicas* (30) are completed

Classifiers with $F \geq 0.95$ all features

All 15 have some with $F \geq 0.80$, whereas EURCHF and USDCNY are not shown below.

Pair	H	T	Frequency			Score		SMA-3	SMA-5	SMA-7	SMA-9	SMA-11	EMA-3	EMA-5	EMA-7	EMA-9	EMA-11	HA	ZZS-level	ZZS-kind	SO	RSI	MACD-S	MACD-E	#	Feat. sel. (ms)		Model (ms)	
			$\downarrow$	$\approx$	$\uparrow$	min	max																				μ	σ	μ	σ
AUDUSD	1	0.01	326	9	323	0.60	0.97	17	4	9	7	3	1	1	0	1	1	2	3	0	3	30	7	3	658	52.79	11.78	1.05	0.06
AUDUSD	1	0.02	318	21	319	0.75	0.97	18	9	1	2	4	3	1	0	0	0	2	3	0	6	30	5	4	658	49.23	6.82	1.03	0.03
BTCUSD	1	0.01	474	3	469	0.66	1.00	18	7	7	5	1	0	1	0	0	1	4	0	2	9	30	7	6	946	56.48	18.77	1.94	0.10
BTCUSD	1	0.02	473	5	468	0.59	0.99	21	8	5	2	3	2	0	0	0	0	7	0	3	10	30	7	6	946	58.78	16.65	1.95	0.08
BTCUSD	1	0.03	469	12	465	0.42	1.00	19	14	3	3	2	0	0	0	0	1	1	0	3	7	30	2	5	946	51.16	13.42	1.93	0.10
BTCUSD	1	0.04	463	19	464	0.62	0.99	22	7	6	3	4	1	1	1	1	0	2	0	1	8	30	4	4	946	53.70	13.60	1.94	0.11
BTCUSD	1	0.05	460	22	464	0.52	1.00	17	11	6	6	4	2	0	0	0	1	2	0	3	8	30	3	5	946	55.31	15.76	1.93	0.10
EURCAD	1	0.02	329	26	329	0.53	0.95	12	9	5	3	1	2	0	1	1	1	5	8	0	1	26	11	6	684	50.06	5.32	1.11	0.06
EURGBP	1	0.01	342	19	335	0.65	0.96	21	7	3	1	0	1	1	1	2	1	0	3	0	10	28	8	3	696	50.45	9.24	1.16	0.06
EURJPY	1	0.01	337	13	347	0.50	0.96	18	10	2	1	4	2	0	1	0	2	1	3	0	6	26	8	7	697	50.96	11.62	1.14	0.12
EURSEK	1	0.01	346	23	343	0.68	0.97	19	7	5	4	2	3	2	1	1	0	1	7	0	3	26	8	4	712	52.61	9.42	1.22	0.08
EURUSD	1	0.01	340	12	334	0.71	0.95	24	1	6	2	2	3	0	2	0	0	2	5	0	6	26	7	5	686	52.69	10.55	1.15	0.07
GBPJPY	1	0.01	322	15	320	0.63	0.95	22	4	4	2	4	1	1	1	0	1	3	1	0	6	29	9	5	657	55.18	17.10	1.06	0.09
GBPUSD	1	0.01	317	10	305	0.61	0.95	15	2	8	4	3	1	3	1	3	0	0	2	0	6	28	14	4	632	54.37	9.76	1.02	0.12
GBPUSD	1	0.02	306	26	300	0.65	0.98	17	2	6	3	6	6	0	0	0	1	5	3	0	3	28	8	5	632	51.61	5.56	0.98	0.04
NZDUSD	1	0.01	332	4	333	0.67	0.96	23	2	8	6	1	3	1	0	0	0	3	2	0	3	28	7	3	669	53.18	10.32	1.09	0.10
NZDUSD	1	0.02	326	20	323	0.53	0.99	19	4	6	0	1	0	0	0	0	1	7	1	0	5	30	9	1	669	48.19	5.83	1.07	0.05
USDJPY	1	0.01	343	13	349	0.54	0.98	17	3	5	4	1	3	1	0	1	2	4	7	0	2	27	11	4	705	54.39	8.62	1.23	0.07
USDMXN	1	0.01	323	11	319	0.67	0.99	15	7	6	3	2	2	0	0	1	0	6	3	0	7	30	10	0	653	54.64	14.25	1.05	0.10
USDMXN	1	0.02	313	28	312	0.73	0.98	18	7	1	2	3	1	2	0	0	2	4	4	0	6	30	14	0	653	53.54	10.75	1.03	0.04
USDRUB	1	0.01	346	8	342	0.63	0.97	17	9	6	2	2	2	0	0	1	1	6	4	0	4	30	8	2	696	55.07	14.56	1.18	0.08
USDRUB	1	0.02	341	22	333	0.64	0.97	16	5	4	5	1	1	1	0	0	0	5	6	0	4	30	5	3	696	49.03	9.01	1.19	0.11

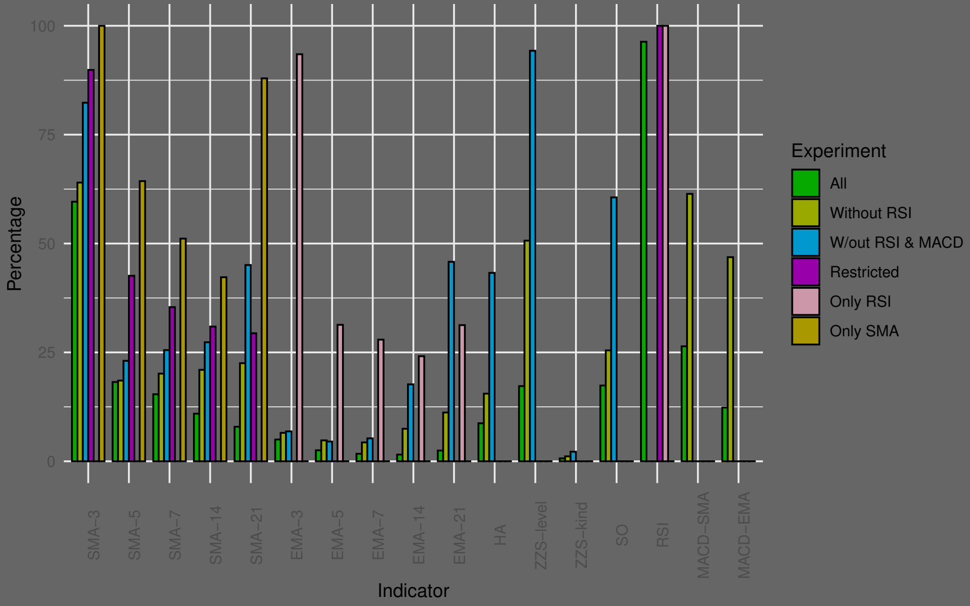
"no change" is too empty 25% of the total combinations

Feature frequency

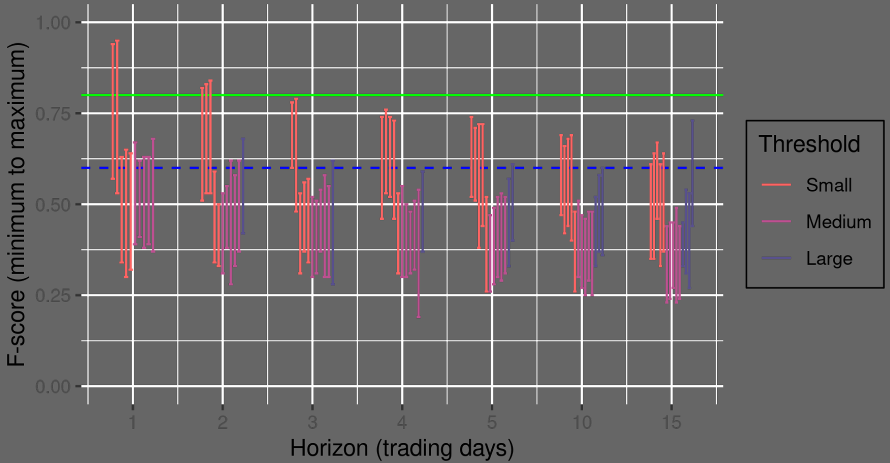
Currency pair	SMA-3	SMA-5	SMA-7	SMA-14	SMA-21	EMA-3	EMA-5	EMA-7	EMA-14	EMA-21	HA	ZZS-l	ZZS-k	SO	RSI	MACD-SMA	MACD-EMA
AUDUSD	58	18	16	14	8	5	4	2	2	4	8	12	0	15	97	29	14
BTCUSD	65	26	16	9	10	4	1	1	1	2	11	2	6	30	100	20	15
EURCAD	53	19	14	14	9	5	3	3	2	4	8	17	1	13	93	41	18
EURCHF	55	16	12	11	8	4	2	1	1	3	7	49	1	12	89	17	13
EURGBP	58	16	17	9	6	6	2	2	2	3	8	16	0	20	99	28	9
EURJPY	61	18	13	12	11	4	2	2	1	3	9	14	0	20	97	22	11
EURSEK	54	18	15	14	9	6	4	2	3	2	9	25	2	14	90	25	15
EURUSD	60	17	18	11	9	5	3	2	2	2	9	15	0	17	97	23	12
GBPJPY	62	19	18	9	9	4	2	2	1	2	9	9	0	20	99	25	14
GBPUSD	58	18	16	12	12	6	4	2	2	3	6	9	0	16	96	36	15
NZDUSD	64	16	17	9	4	4	2	1	1	2	11	8	0	16	98	31	11
USDCNY	58	16	14	8	4	5	2	2	1	1	7	54	0	14	97	14	9
USDJPY	58	18	16	13	7	6	3	2	2	3	9	13	0	17	95	24	13
USDMXN	60	19	13	10	7	6	3	1	1	2	11	8	0	21	99	39	5
USDRUB	70	19	16	9	6	5	1	1	1	1	9	8	0	16	99	22	11

Six experimental setups

All	RSI dominates; all 15 have some with ≥ 0.80
-RSI	MACD is getting popular; scores similar
$\Uparrow$ -MACD	EMA (longest) and HA enter the scene; scores similar
RSI+SMA	Still all good
RSI+EMA	Chinese Yuan can no longer be predicted well
SMA	All is fine again for short horizons and small thresholds

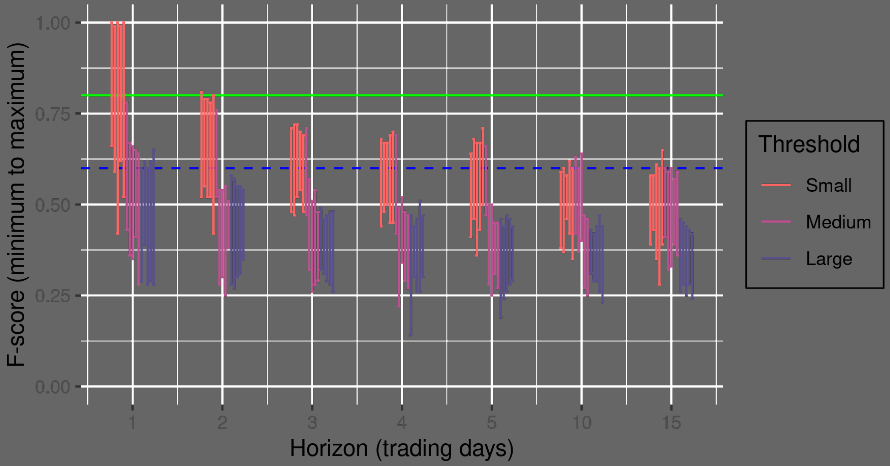

Percentage
100
75
50
25
0
SMA−3
SMA−5
SMA−7
SMA−14
SMA−21
EMA−3
EMA−5
EMA−7
EMA−14
EMA−21
HA
ZZS−level
ZZS−kind
SO
RSI
MACD−SMA
MACD−EMA
Indicator
Experiment
All
Without RSI
W/out RSI & MACD
Restricted
Only RSI
Only SMA

EURCAD



F-score (minimum to maximum)
1.00
0.75
0.50
0.25
0.00
1
2
3
4
5
10
15
Horizon (trading days)
Threshold
Small
Medium
Large

BTCUSD



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1.00
0.75
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1
2
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Horizon (trading days)
Threshold
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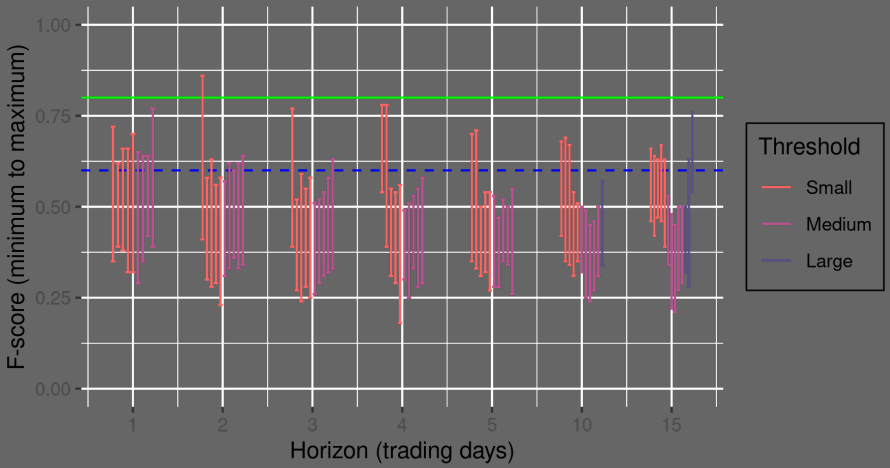
Medium
Large

USDCNY



F-score (minimum to maximum)
1.00
0.75
0.50
0.25
0.00
1
2
3
4
5
10
15
Horizon (trading days)
Threshold
Small
Medium
Large

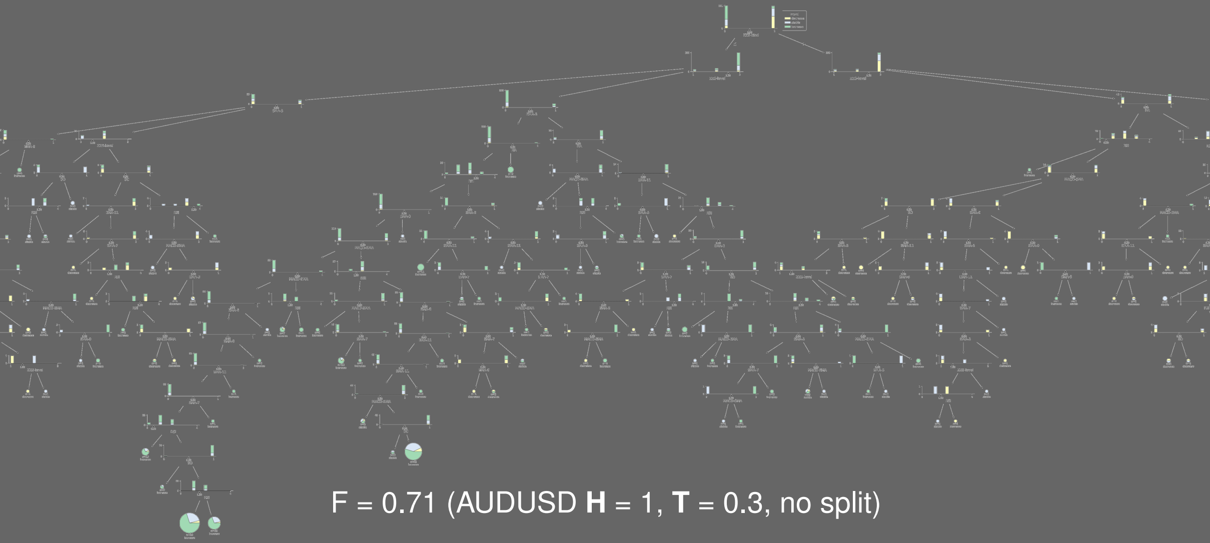
Computational load

CPU	16-core i7-10700K
RAM	64 GB
Characterization	$\approx$ two seconds per pair; completely deterministic
Feature selection	$\leq$ 70 ms, some variation (for a sample)
Training	$\leq$ 2 ms, little variation, per replica
Experiments	a few hours

Decision tree using RSI and SMA-3

F = 0.77 (USDCNY **H** = 2, **T** = 0.01, no split)

Decision tree for all features



F = 0.71 (AUDUSD **H** = 1, **T** = 0.3, no split)

Conclusions

We extract indicators and price changes from forex data

We use *(fuzzy) rough sets* to represent them

Given the current values, we predict trend ($\downarrow, \approx, \uparrow$)

This is feasible with very simple indicators

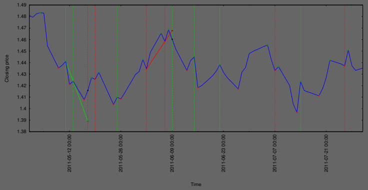
We can tell which ones are relevant for the forecast

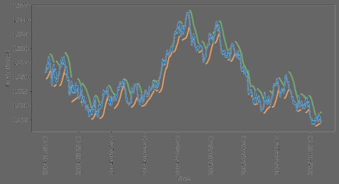
Feasible **short** forecast horizons and **small** thresholds

For longer horizons and larger thresholds, this is not all settled yet

Future work

1. Additional **indicators**, finer **discretization**
2. More use to the <u>fuzziness</u>
3. Different *feature selectors* and *classifiers*
4. Visualize the rough sets
5. Hourly or minute-level data (this was daily data)
6. Stock-market data





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