Deep Reinforcement Learning for Trading

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What Is Reinforcement Learning?

- Crossover between supervised and unsupervised learning
- Solving the problem of delayed reward
- For every state we perform and action based on the state and prior experience
- A chain of actions leads to a reward (win/loss)
- Every action in the chain can be assigned a fractional reward

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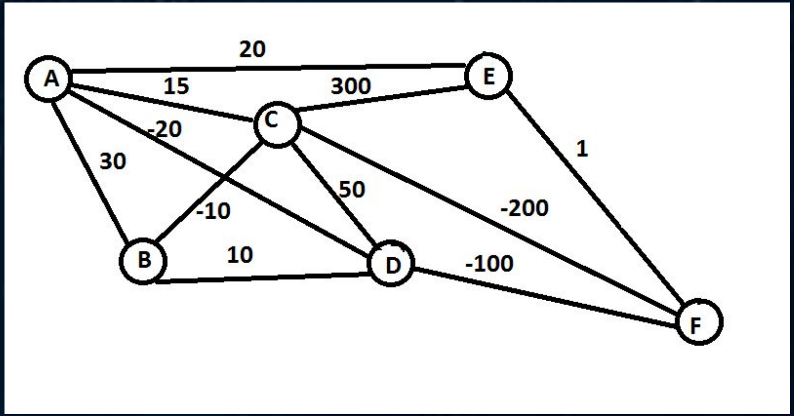
Elements of Reinforcement Learning

- Markov decision process
- Take action (A)
- Transition to state (S)
- Get reward (R)
- A policy (π) defines the set of actions
    - Probability of taking an action from a particular state
- The reward we get defines our value (V)



Maximise: $E\,(r_t \mid \pi_t\, s_t)$

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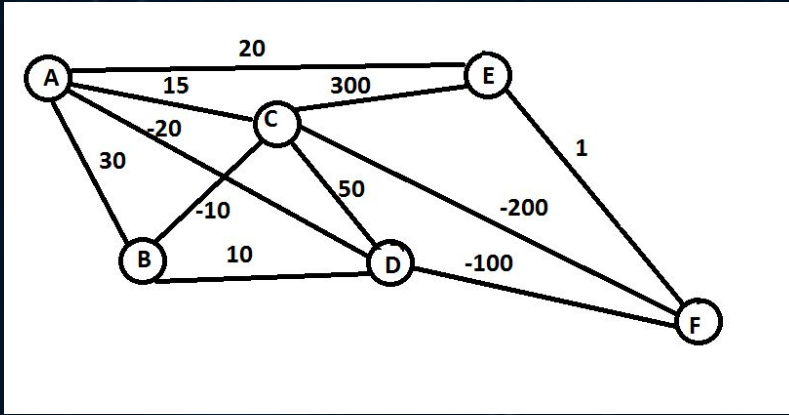
Choosing a Policy

- Pick the lowest value at each node
  - Epsilon-greedy
- Not the optimal policy
- Exploration vs exploitation



With some exploration we might achieve better Value!

The actions we took **before** we got into a situation with high reward deserves some credit too (not quite as much but some).

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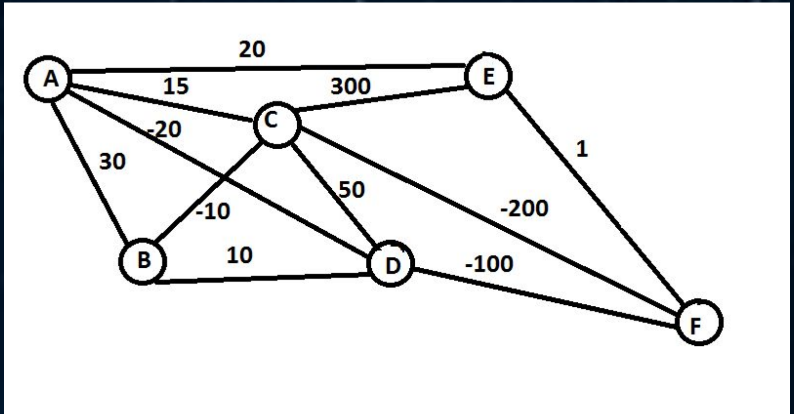
Calculating the Value of an Action

- We retroactively apply rewards up a chain of memories
- Certain actions are preferable even if they don't lead to reward
- We define an "action value function" (Q)
- Q defines the value of action a in state s



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Q - Tables

- Traditional RL uses tables (Q-tables) to calculate the action-value-function
- We can now use deep learning to estimate Q

Game Board:

Current state (s): 000 010

Selected action (a): →

Reward (r): 0

Next state (s'): 000 001

max Q(s'): 1.0

Q Table: $\gamma = 0.95$

	000 100	000 010	000 001	100 000	010 000	001 000
↑	0.2	0.3	1.0	-0.22	-0.3	0.0
↓	-0.5	-0.4	-0.2	-0.04	-0.02	0.0
→	0.21	0.4	-0.3	0.5	1.0	0.0
←	-0.6	-0.1	-0.1	-0.31	-0.01	0.0

New $Q(s,a) = r + \gamma * \max Q(s') = 0 + 0.95 * 1 = \mathbf{0.95}$

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Bellman Equation

$$Q(s,a) = r(s,a) + \gamma \max Q(s',a)$$

- r is the "immediate" reward of action a
- Q is the "cumulative" reward of an action a
- s' is the state we end up with after performing action a
- We see that we are actually stepping "backwards"
- γ is called the discount factor
    - For γ close to one we get more greedy

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Practical Consideration

1. **“Gamification”** of trading
2. How is the system trained (each game independent)?
3. Reward-function engineering
4. What features do we use for the neural network?
5. How to test the system?
6. What type of ANN should be used?

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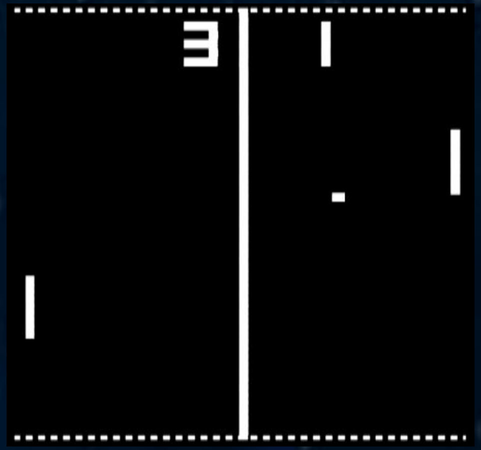
1) Gamification

- Computer games in their simplest form have:
  - State
  - Cursor movement
  - Reward
- For a trading game this would be equivalent to:
  - Historical and current prices, technical data and alternative sources
  - Buy/Sell/Do Nothing
  - PnL



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2) How To Train The System?

- Each entry and exit is an individual game
- Run through the price series sequentially or randomly
- Make the whole price series one single game
- Train on each instrument separately or on all with the same learner

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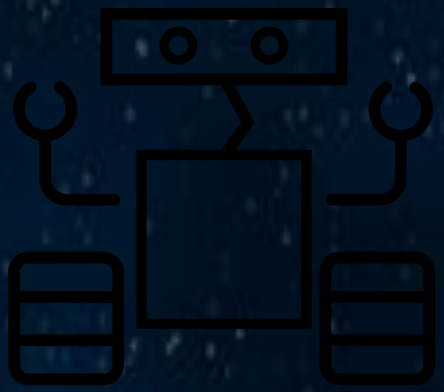
3) Reward Function Design

- Pure PnL on exit, otherwise zero
- PnL from start of trade to every time step t
- PnL per tick
- Punishment for long hold times
- Alternatives to PnL:
  - Recognition of trading direction
  - Recognition of correct regime



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4) What Features To Use

- OHLCV
- Technical indicators
- Time of day, day of week, time of year
- Different time granularity
- Other instruments
- Alternative data

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5) How To Test the System

- Sine waves
- Trend curves
- Random walks
- Different types of autocorrelation
- Adding noise to “clean” test curves
- Recurring patterns

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6) What Type of Algorithm?

- Standard neural network
- Convolutional NN
- LSTM

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Sine Wave - Trend - No Noise

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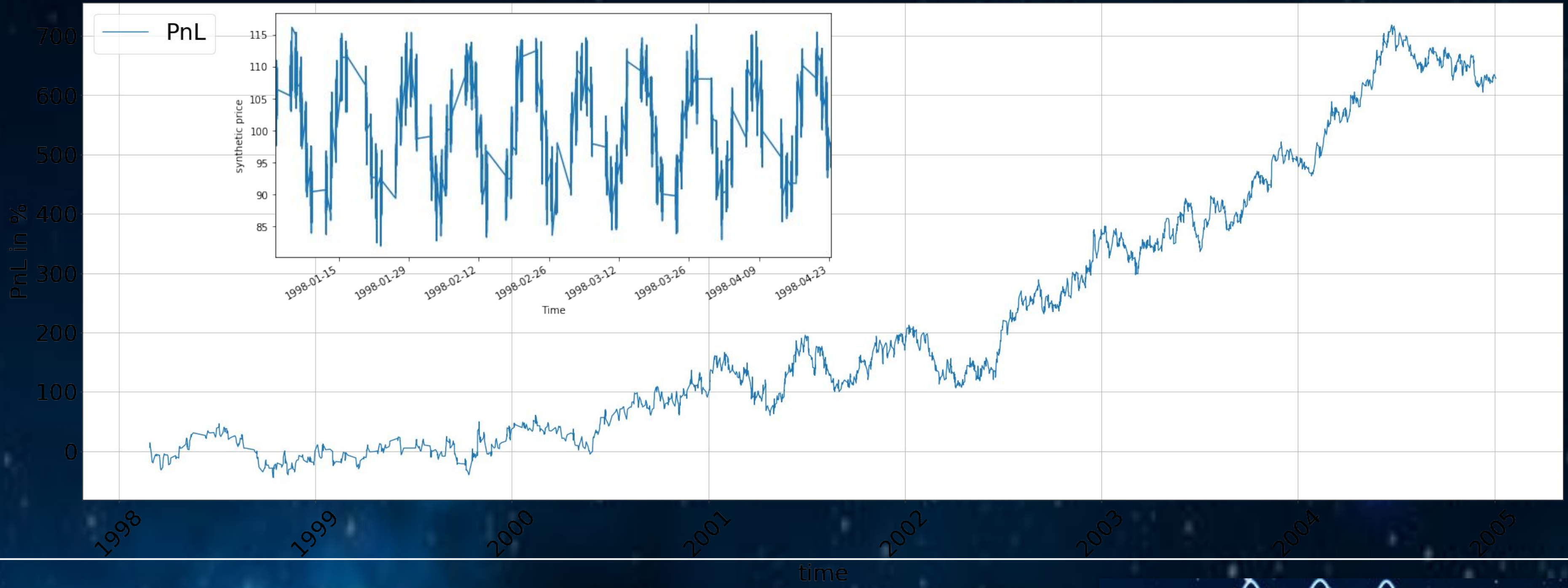
Synthetic Price - Since Wave With Noise



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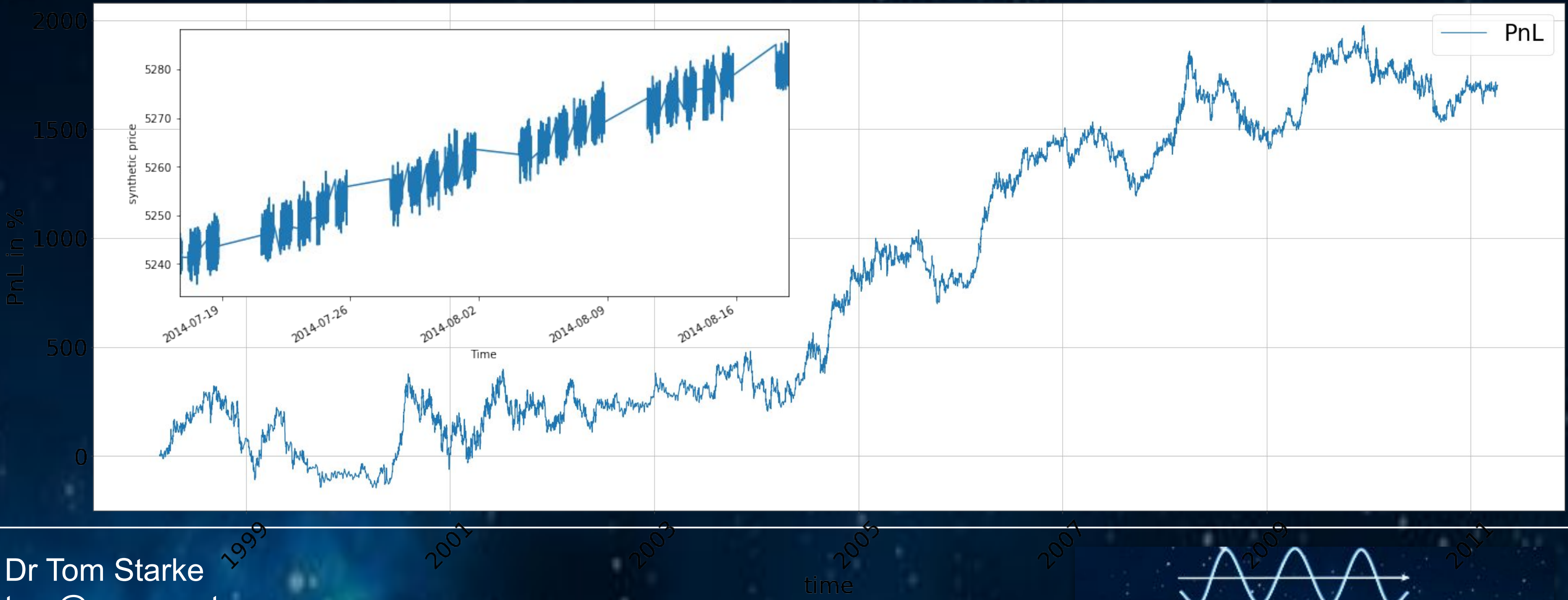
Trend With Noise



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Lessons To Be Learned

Ref: https://www.alexirpan.com/2018/02/14/rl-hard.html

- RL can be very sample inefficient
    - Even for a simple Atari game RL needs 70 million frames to achieve human performance
        - Distributional DQN (Bellemare et al, 2017)
- Reward function design is hard
- Rewards in trading are sparse
- Local optima are hard to escape
- RL could just be overfitting peculiar chart patterns
- Results are unstable and hard to reproduce

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What Makes RL So Hard?

- Financial time series are very noisy
- Financial systems are dynamic - rules keep changing
- Rules evolve by the very act of understanding them
- Computing power is still limited
- New algorithms are yet to be discovered

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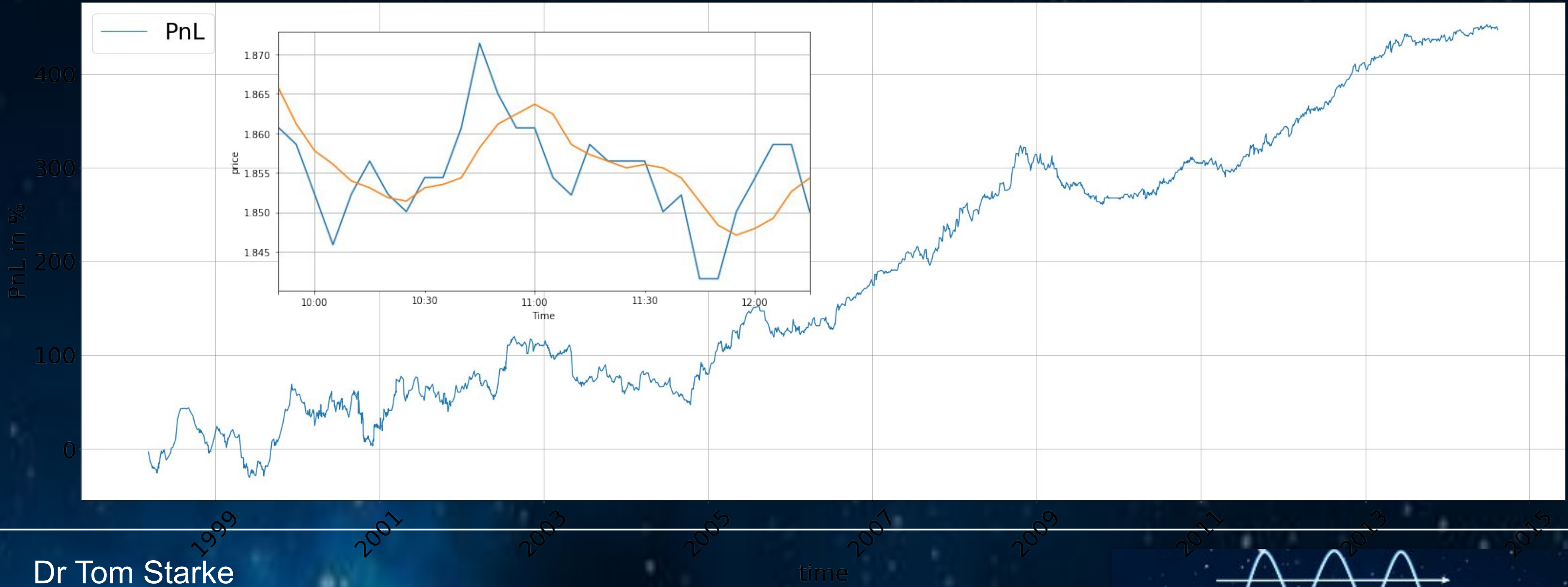
Performance with 5-period SMA smoothed price curve



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