



Machine learning applied to the optimal operation of the uruguayan energy system

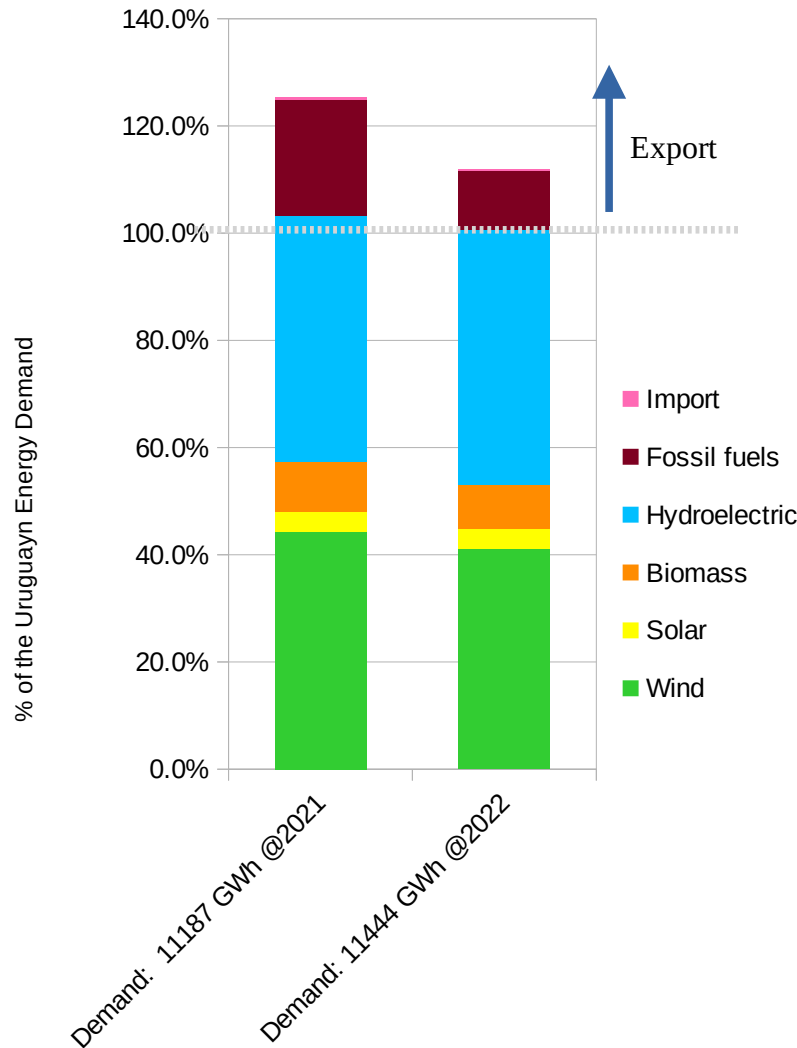
Ruben Chaer - March 6, 2023

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Montevideo - Uruguay

- One of the main tasks of ADME is the operation of the national electrical system to guarantee the supply of energy at a minimum cost.
- The purpose of this presentation is to tell you how we are using Machine Learning for this task and to comment on some particular aspects of this field of application.

Uruguayan Energy Market



- Uruguay's generation matrix is 90% renewable. Approximately 10% based on biomass, 30% on wind and solar and 50% hydropower.
- Wind and Solar are variable in terms of hours but firm in terms of weeks.
- Hydropower is stable in terms of hours but has strong annual variability.
- These random components result in a cost of the future operation with huge dispersion.

White paper:
**Operación óptima
de los recursos de
generación de
energía eléctrica
(spanish)**



The optimal dispatch of generation resources is a Stochastic Dynamic Programming problem.

The use of stored resources (water) today reduces the operating costs of the present but increases those of the future, and vice versa.

An optimal policy is one that reduces the expected value of the future operating cost of the system.

Min <Future Cost>

At the optimum, the variations of Present vs. Future are in equilibrium.



Dynamic Programming 1957

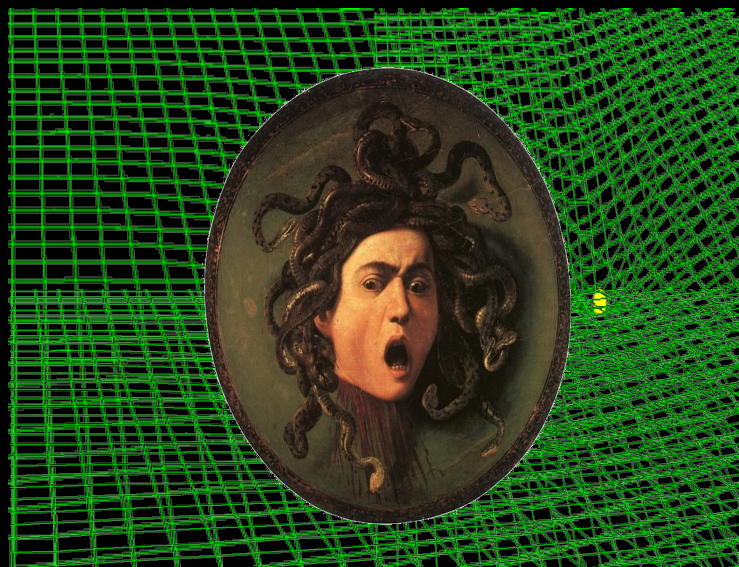
Bellman recursion

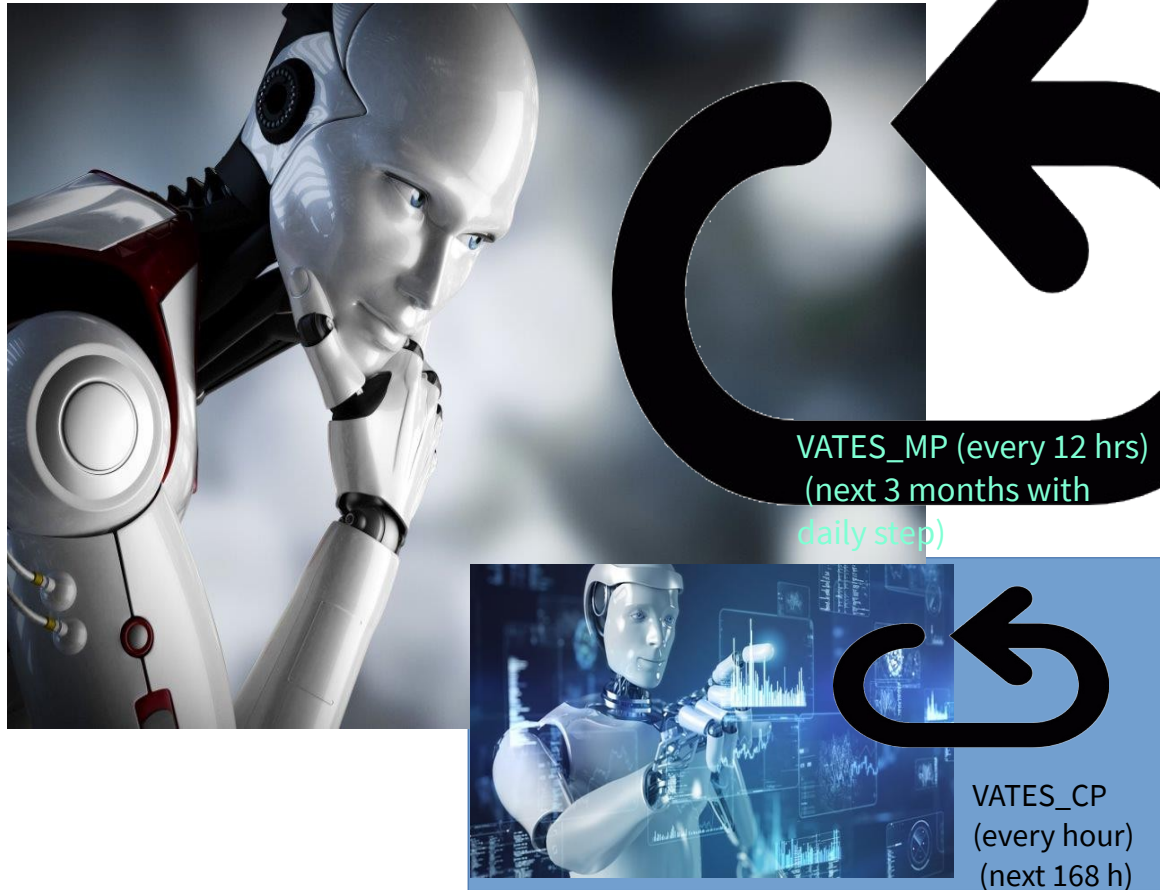
$$CF(X, k) = \left\langle \min_{u_k} \left\{ sc(X, u_k, r_k, k) + \rho FC(X_{k+1}, k+1) \right\} \right\rangle_{\{r_k, r_{k+1}, \dots\}}$$



Richard Ernest Bellman (1920–1984)

Bellman's Curse of Dimensionality

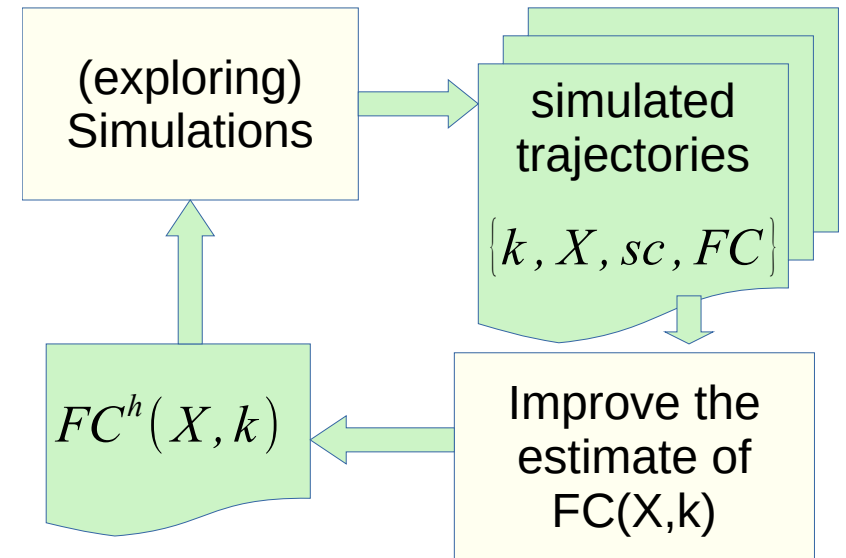
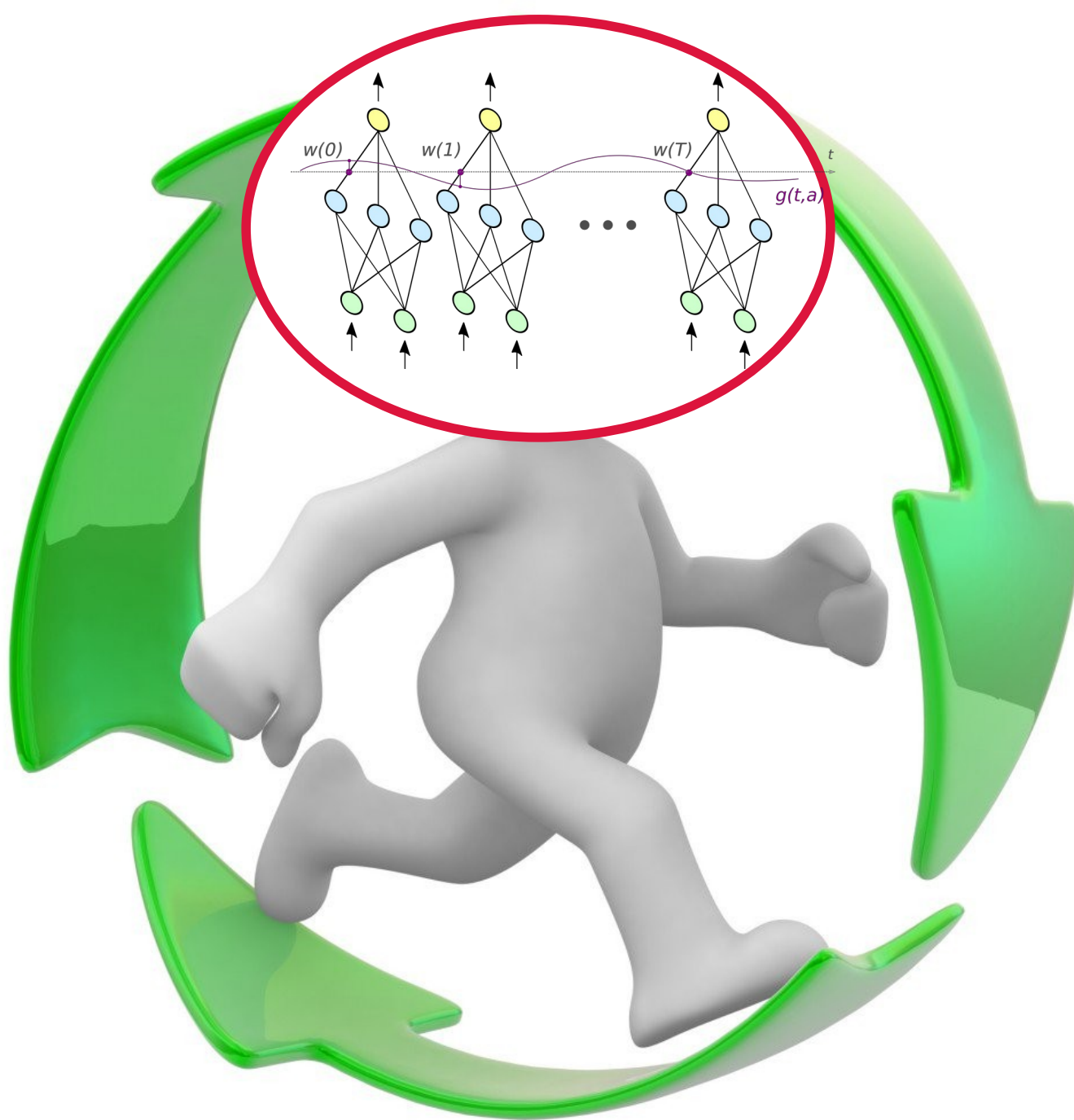




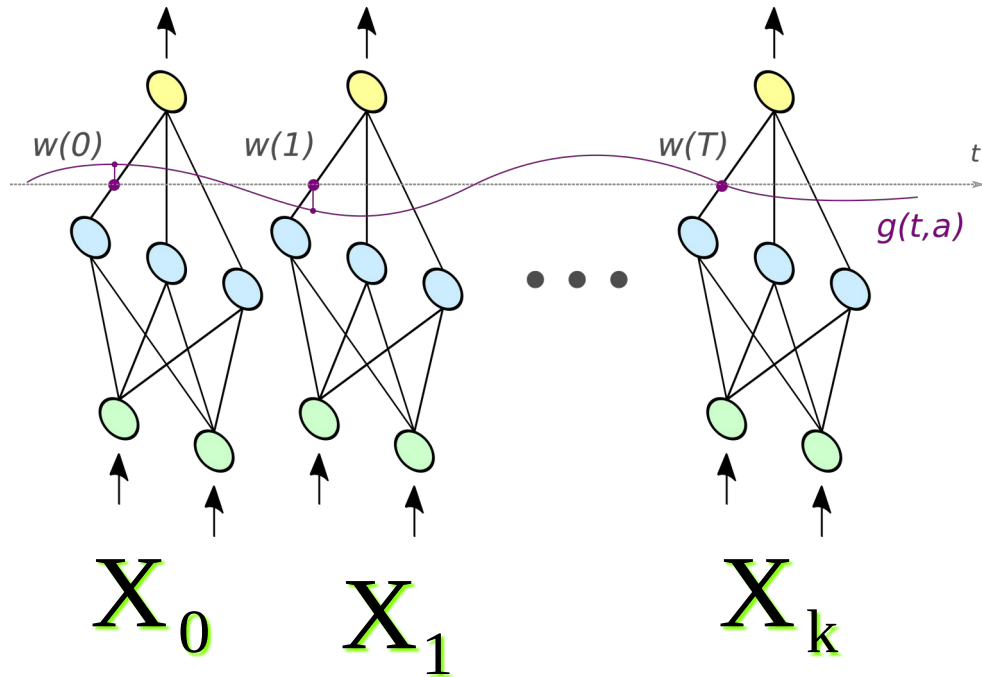
- At ADME we have two Robots that are permanently solving the optimal dispatch.
- Both assimilate the information on the state of the system and on the forecasts of rainfall, wind, solar radiation and Demand and resolve the optimal operation policy.
- One Robot analyzes the next three months with daily detail and publishes the results twice a day.
- The other analyzes the next seven days with hourly detail and publishes the results every hour.
- Both robots use the Bellman Recursion, which condemns us to not be able to continue adding state variables and details to the system model.
- This led us to develop a new generation of Robots based on Artificial Intelligence techniques to try to escape the Bellman Curse.

2nd generation of robots with artificial intelligence

VatesIA_MP y VatesIA_CP



FC(X) representation and regularizations



$$L = \sum_{k,g} L_{kg} + \lambda \sum_k \|\theta_k\|^p + \beta \sum_{k=2} \|\theta_k - \theta_{k-1}\|^2$$

- Parsimony(t)
- TD
 - Power series and harmonics

- $p=2$: Ridge
- $p=1$: Lasso

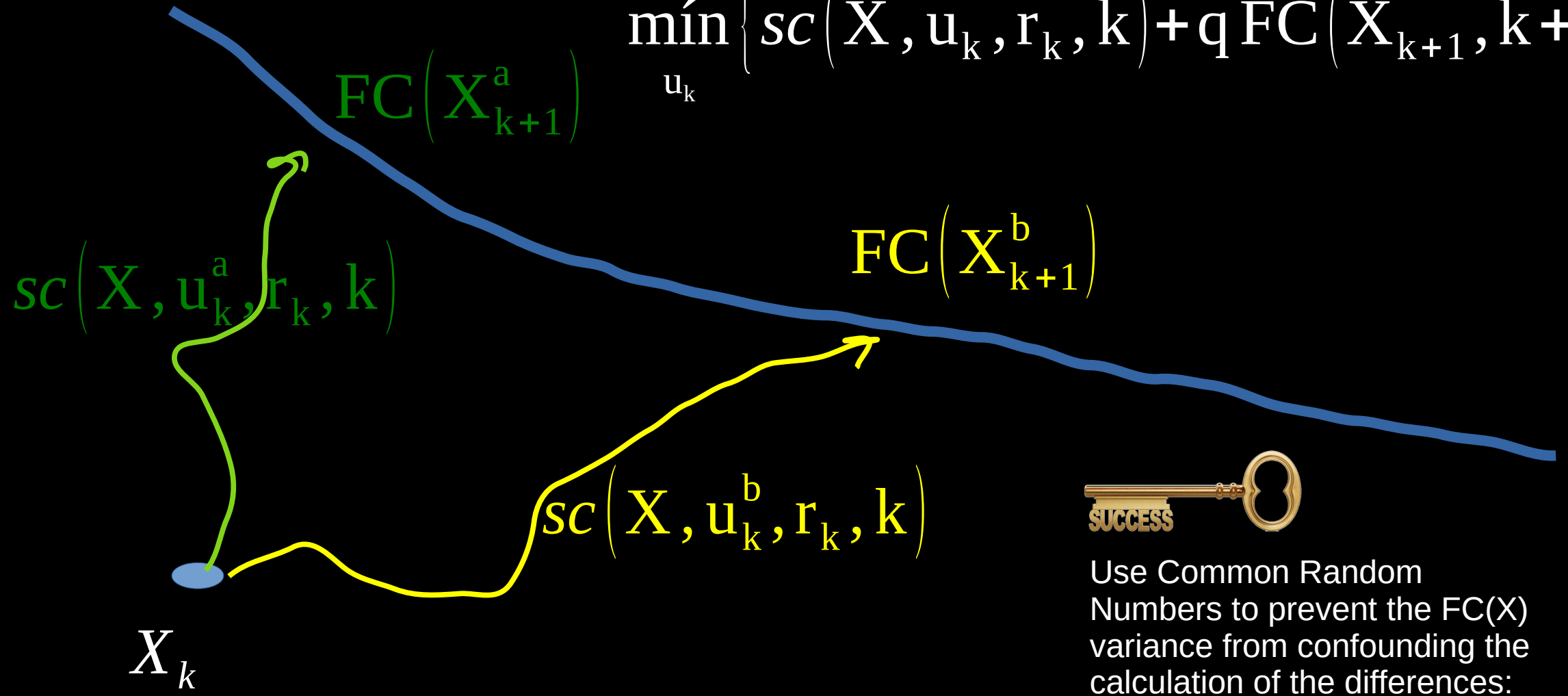


Approximate the differences instead of the function itself

$$L_{kg} = \frac{1}{4N^2} \sum_{i \neq j \in g} ((M(X_{kj}, \theta_k) - M(X_{ki}, \theta_k)) - (FC_{kj} - FC_{ki}))^2$$

The information is in the $FC(X)$ differences

$$\min_{u_k} \left\{ sc(X, u_k, r_k, k) + q FC(X_{k+1}, k+1) \right\}$$



Use Common Random Numbers to prevent the $FC(X)$ variance from confounding the calculation of the differences: $FC(X_a) - FC(X_b)$ at the arrival states

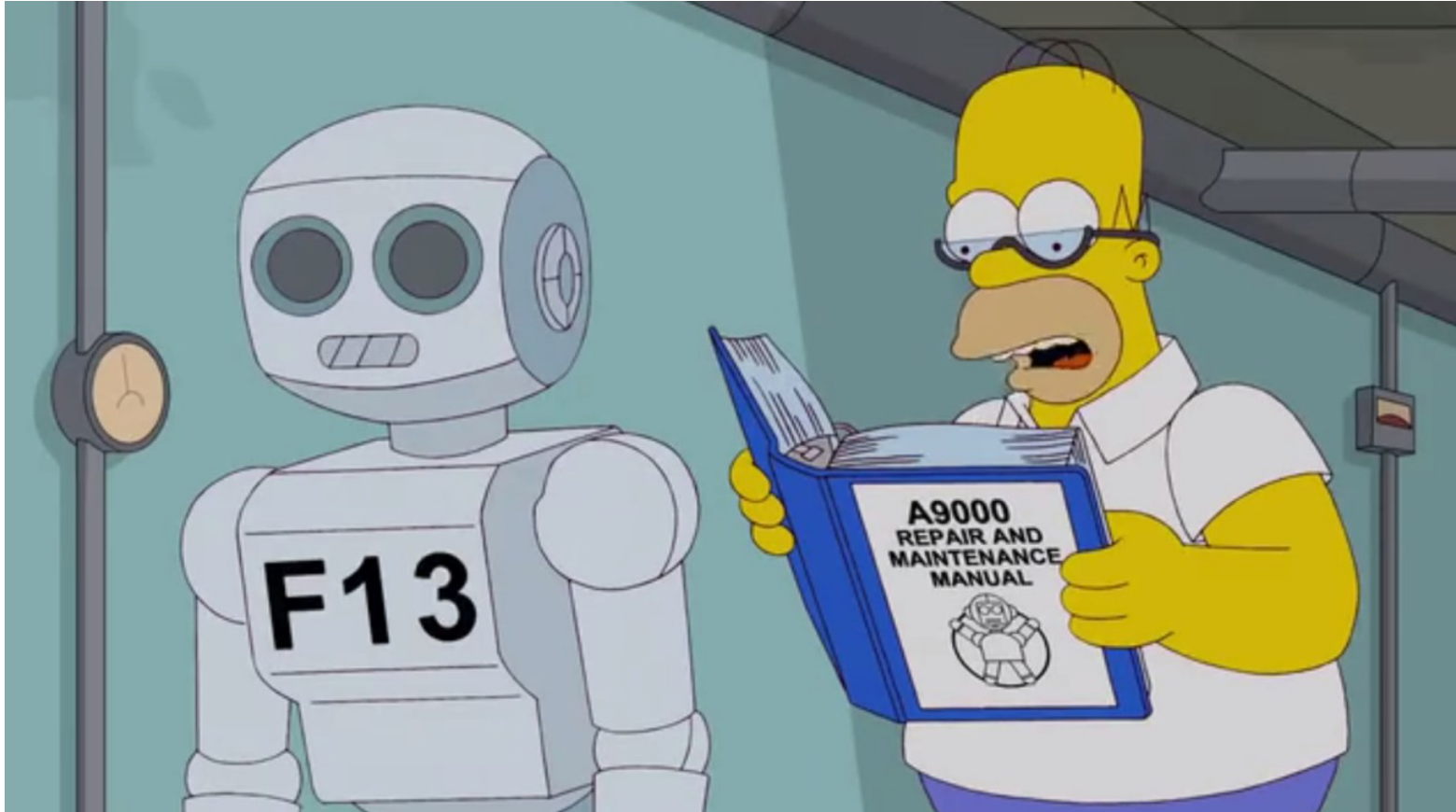
Exploration Strategies



In a stable system, the use of CRN leads to convergence of trajectories and a consequent loss of exploration capability. Each NTD steps states are exploited to recover said capability.



In a continuously operated system, learning is also processed continuously. With the course of each real hour, the vector of neurons is moved, discarding the one corresponding to the elapsed hour and repeating the last neuron of the set to continue in the learning loop



That's all folks!

**Thank you for your
attention.**

