Plasma Profile Prediction and Control in Tokamaks

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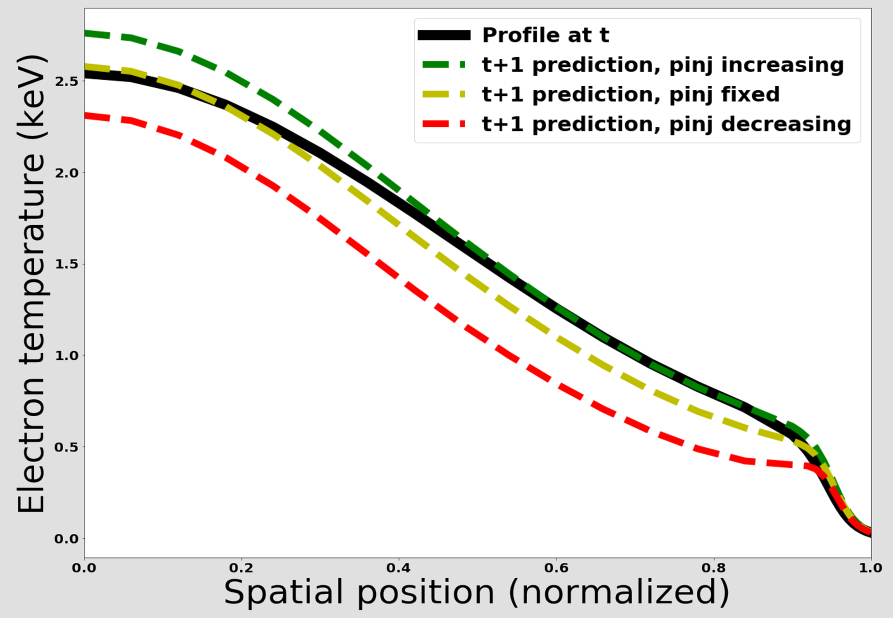
Purpose

Tokamaks are the most developed type of experimental fusion reactor. They require careful tuning of actuator signals that heat, spin, and shape the plasma. The plasma can be described by the plasma's temperature, density, pressure, current, and rotation profiles.

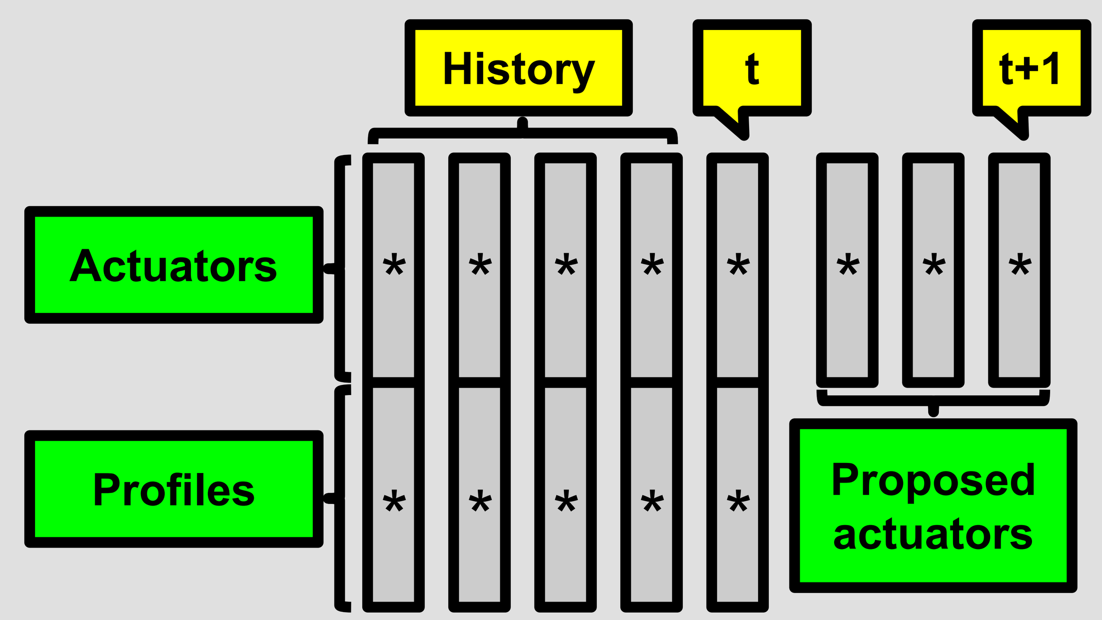
Experimental tokamak research entails physicists from all over the world submitting experiment proposals to tokamak operators. Currently, operators and physicists often **predefine** the paths that actuator signals will take during the experiment. However, lots of trial and error is necessary to understand how actuator paths will correspond to changes in plasma state.

Our work aims to tune the actuator signals in real time to more efficiently pursue a given plasma state. The fundamental steps are to

1. **predict** how the profiles are expected to evolve under various actuator conditions, then
2. **control** the plasma: choose the actuator conditions that yield the most desirable predicted profile.



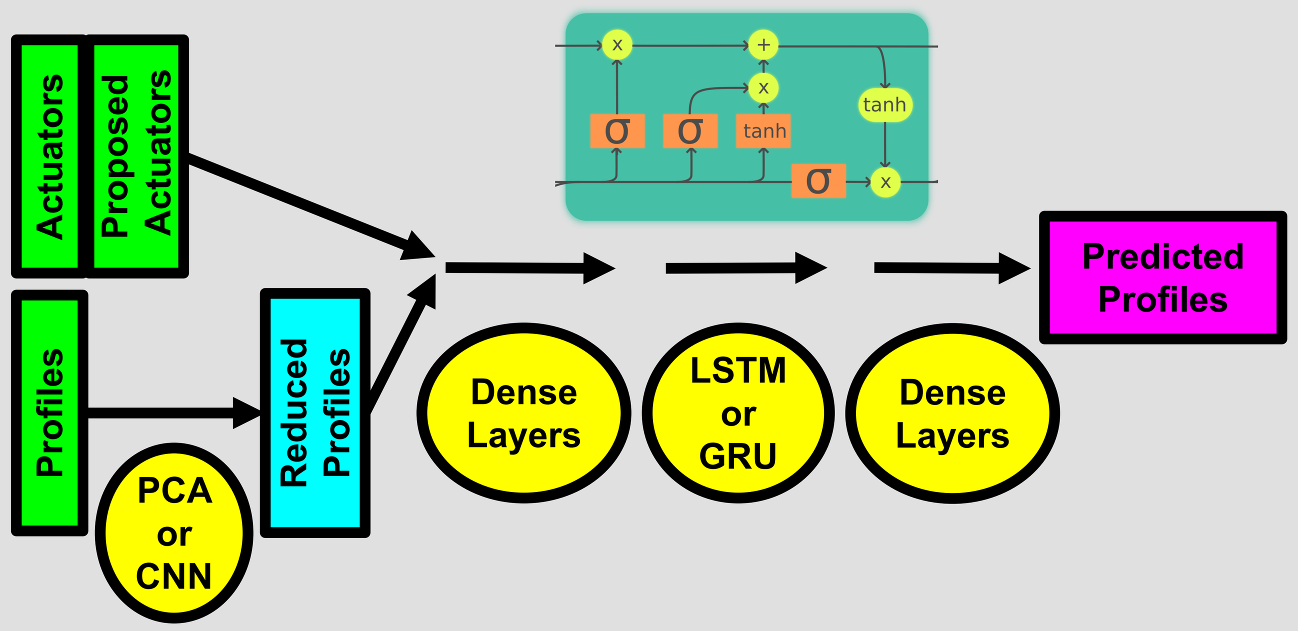
Our algorithm predicts the evolution of the plasma profile under various actuator conditions. Here an increasing, fixed, and decreasing "pinj", or injected heat power, actuator cause the plasma temperature to (respectively) increase, decrease slightly, or decrease by a lot. If the user desiers a temperature higher than 2.5 keV, the algorithm would therefore set the injected heat power actuator to increase.



Input to the algorithm: a time history of the plasma state and past actuators, along with a set of "proposed" actuators for future timesteps. The algorithm outputs a prediction for the plasma profiles at time t+1.

Prediction

Physics-based models for profile prediction take many hours to run. Meanwhile, tokamak plasmas evolve on a timescale of 10-100 milliseconds, requiring realtime algorithms that run in about a millisecond. We are developing a neural-network-based model which takes just a few tens of microseconds to run.



Generalized model architecture used for plasma profile prediction. The profiles are reduced via Printipal component analysis or a trained convolutional neural net. Time-dependence is handled via a Long Short-Term Memory or Gated Recurrent Units Network.

Control

We are now in the final stages of development for the first iteration of the profile **prediction** algorithm. An experiment is currently being run on the DIII-D tokamak to ensure it is capable of running in real time and communicating with the diagnostics (which compute profiles) and actuators.

The inside of the DIII-D Tokamak in San Diego, California. A preliminary version of our algorithm is being tested at the facility this week.

DIII-D Profiles

•Electron temperature
•Electron density
•Ion temperature
•Ion density
•Plasma rotation
•Plasma current
•Plasma pressure
•Safety factor (q)

DIII-D Actuators

•Neutral beam: power
•Neutral beam: torque
•Puffed gas
•Electron Cyclotron Heating power
•Total plasma current

The next step will be to use our prediction to **control** the plasma by guiding it to a desired state. The physicist should be able to supply their desired plasma state in one of two forms:

1. A metric for "good" performance for which the algorithm can optimize. For example, the physicist may want the highest temperature possible while maintaining a certain threshold of stability.
2. An end-profile toward which the physicist would like the plasma to be steered.