Elettra
Sincrotrone
Trieste

Automation, performance optimisation & ML @ Elettra

G. Gaio

Outline

✓ Reinforcement Learning in a Free Electron Laser

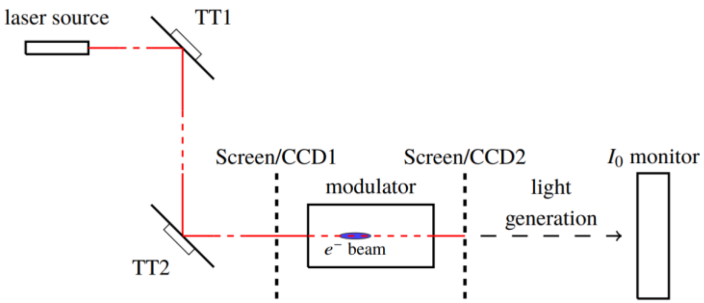
✓ Toward an accelerator autopilot

Reinforcement Learning in FERMI FEL optimization

✓ **Study goal:**
Apply Reinforcement Learning to automatically overlap the seed laser with the electron beam optimizing the radiation intensity

✓ **Seed Laser alignment system:**

- 2 planar Tip-Tilt mirrors (TTs) paired with 2 piezo-motors (hor - ver)
- 2 screens based on Charged-Coupled Devices (CCDs)

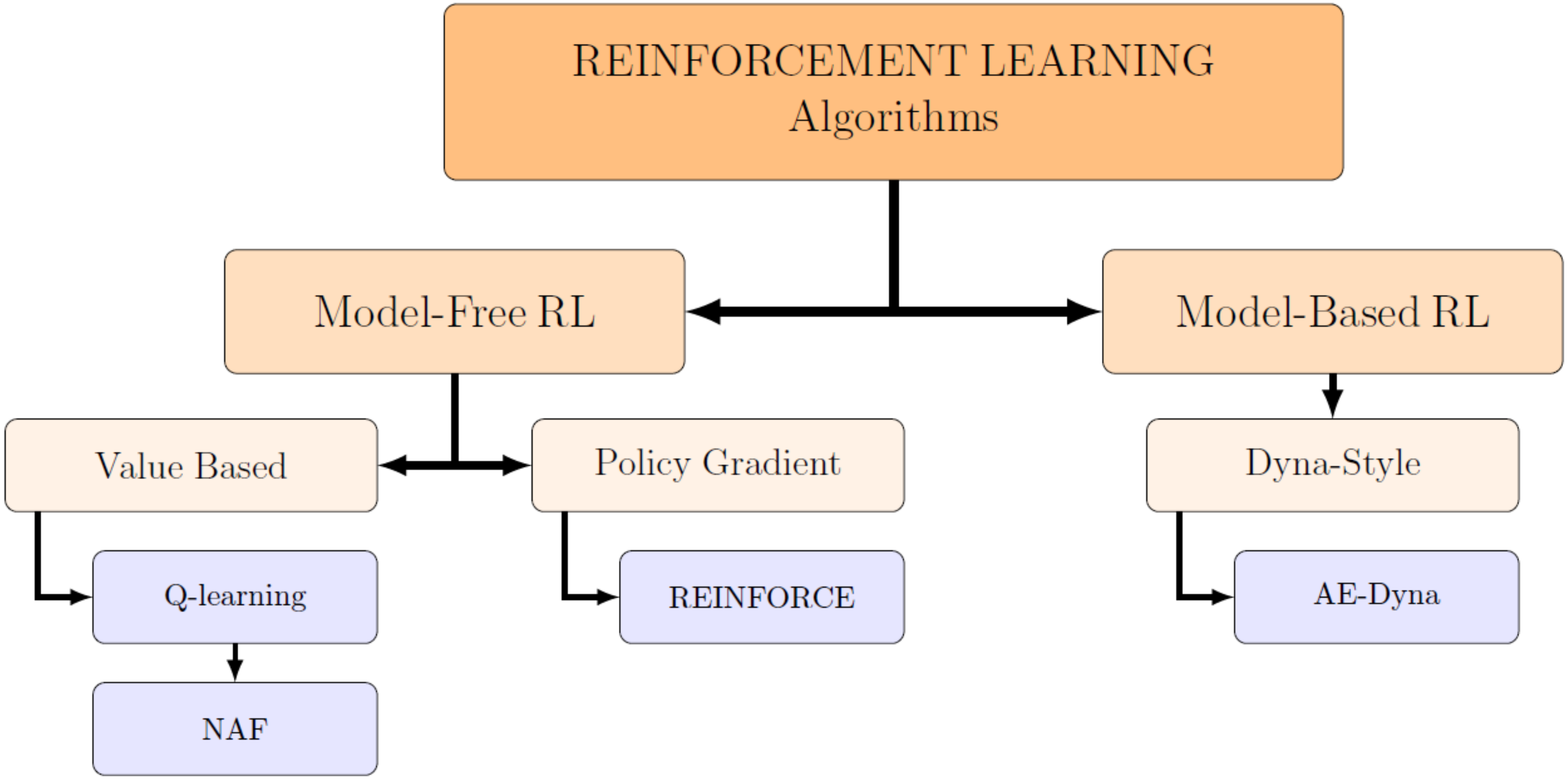


✓ **Final output:**
Intensity acquired by I_0 monitor

Optimization of 4 variables

Niky Bruchon, PhD of University of Trieste
https://arts.units.it/retrieve/handle/11368/2982117/362563/PhD_Thesis_Final_NikyBruchon.pdf

Reinforcement Learning algorithms applied on FERMI



collaboration with CERN

(V. Kain, S. Hirlander)

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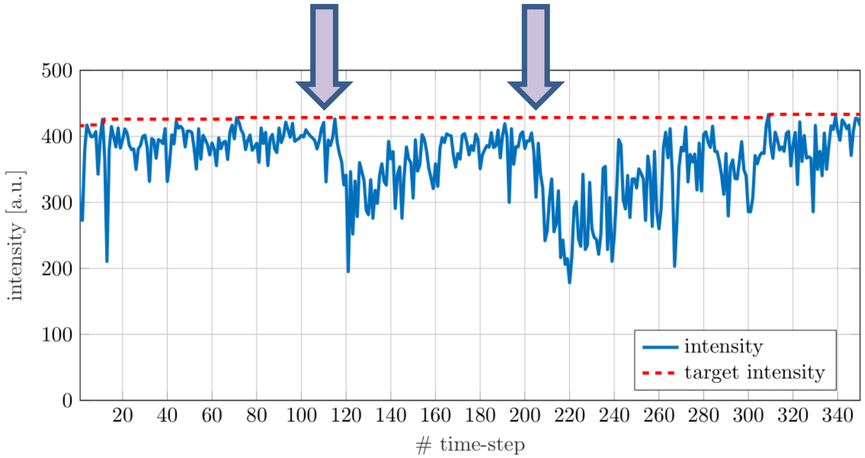
Reinforcement Learning results

Recover from manually imposed perturbation (NPG Reinforce)



Policy gradient methods for free-electron laser and terahertz source optimization and stabilization at the FERMI free-electron laser at Elettra
F. H. O'Shea, N. Bruchon, G. Gaio – PRAB 2020

Attainment of the optimal working point starting from random initial conditions

Algorithm	Training data points	Mean num. of steps	Normalized final intensity
Q-learning	3128	11.28	-
NAF	1074	2.56	1.0019
NAF2	824	2.64	0.9995
AE-Dyna (TRPO)	450	4.46	1.0150
AE-Dyna (SAC)	500	3.28	1.0427
GradAscent	1024	3.82	0.9911
iLQR	1024	2.54	1.0019

Not RL

CERTIFIED MANAGEMENT SYSTEM
CQY CERTIQUALITY
UNI EN ISO 9001:2015
UNI ISO 45001:2018

Toward an accelerator autopilot

- ✓ **Decrease ''virtually'' to 0 the number of clicks** on graphical panels in the control room

⬇

- ✓ Move human knowledge and logics inside GUIs **to server side** (*TANGO devices*)

⬇

- ✓ Develop an infrastructure that can scale easily with the complexity of the logics and allows a fast deployment of automatic optimization / feedback systems

⬇

- ✓ Machine physicists and operators should become the developers / mantainers of the logic of the infrastructure

Behavior Trees (BT)

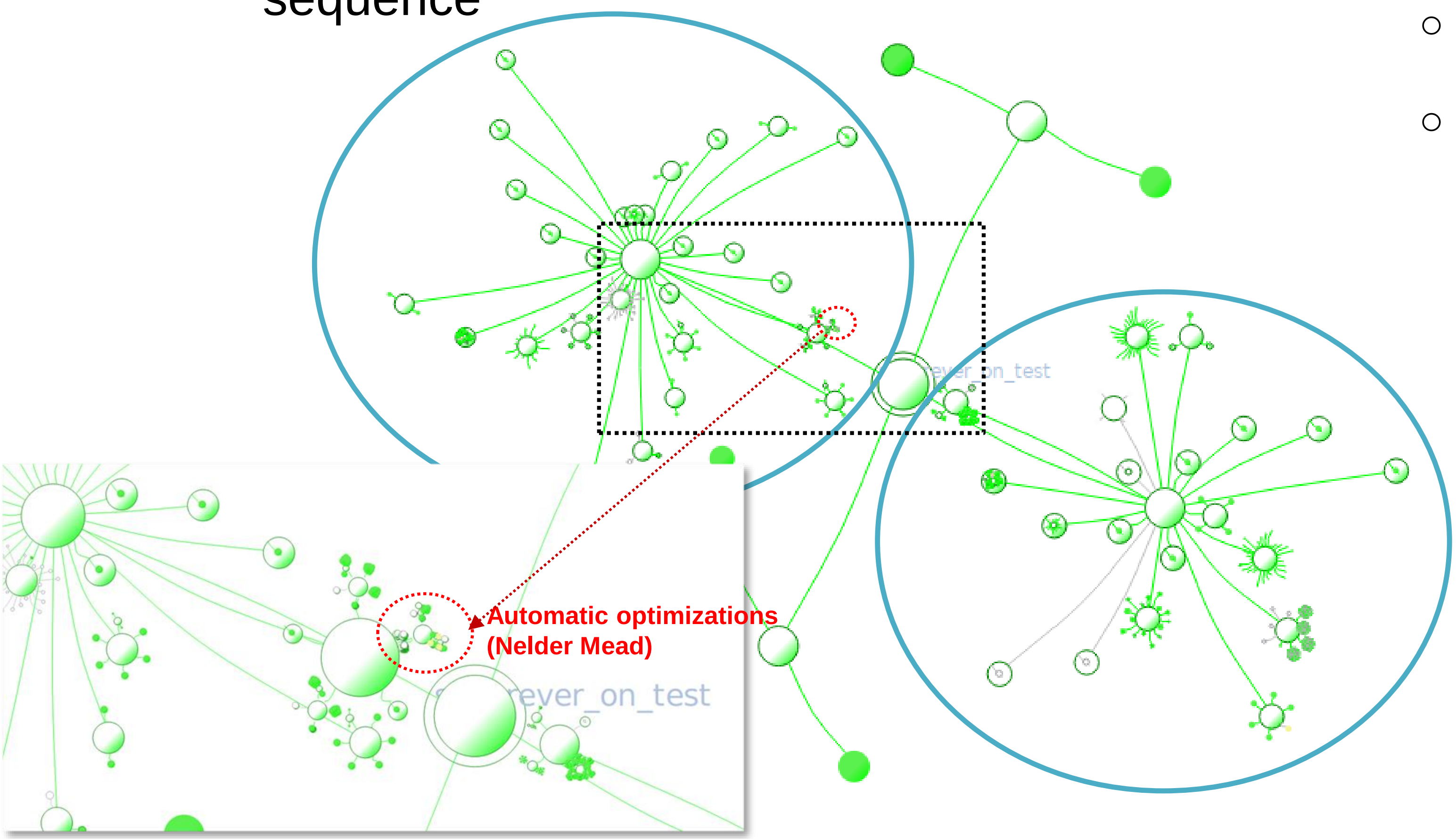
- ✓ BT are used for **in-game AI player opponents**, **UAV** and **robotics**
- ✓ They are able to create very complex tasks composed by simple decoupled self-contained tasks, regardless how they are implemented
- ✓ The tree-structure is composed by:
  - a root node
  - intermediate nodes (composite, selector, decorator) that control the flow
  - leaf nodes
- ✓ In the control system:
  - Each **leaf/node is a TANGO device** that executes a specific task (leaf) or launch in series or parallel other tasks (intermediate/root node)
  - In-house basic scripting language to execute simple reading/setting of variables after receiving a Start command; it supports if/else statement;
  - Can execute *Python*, *Matlab,* bash scripts…
  - Native support of **retry** and **fallback** actions
  - It controls a programmable TANGO device server which implements **feedback** / **numerical optimization schemes**
  - At Elettra BT are known a **SEQUENCERS**

A framework for high level machine automation based on behavior tree - in submission to ICALEPCS2021

Elettra full automation

- ✓ Recover beam loss
- ✓ Injection, beam to users
- ✓ It manages:
  - *HW devices*
  - *Optics correction*
  - *Slow/Fast Orbit Feedbacks*
  - *Automatic Optimizations*

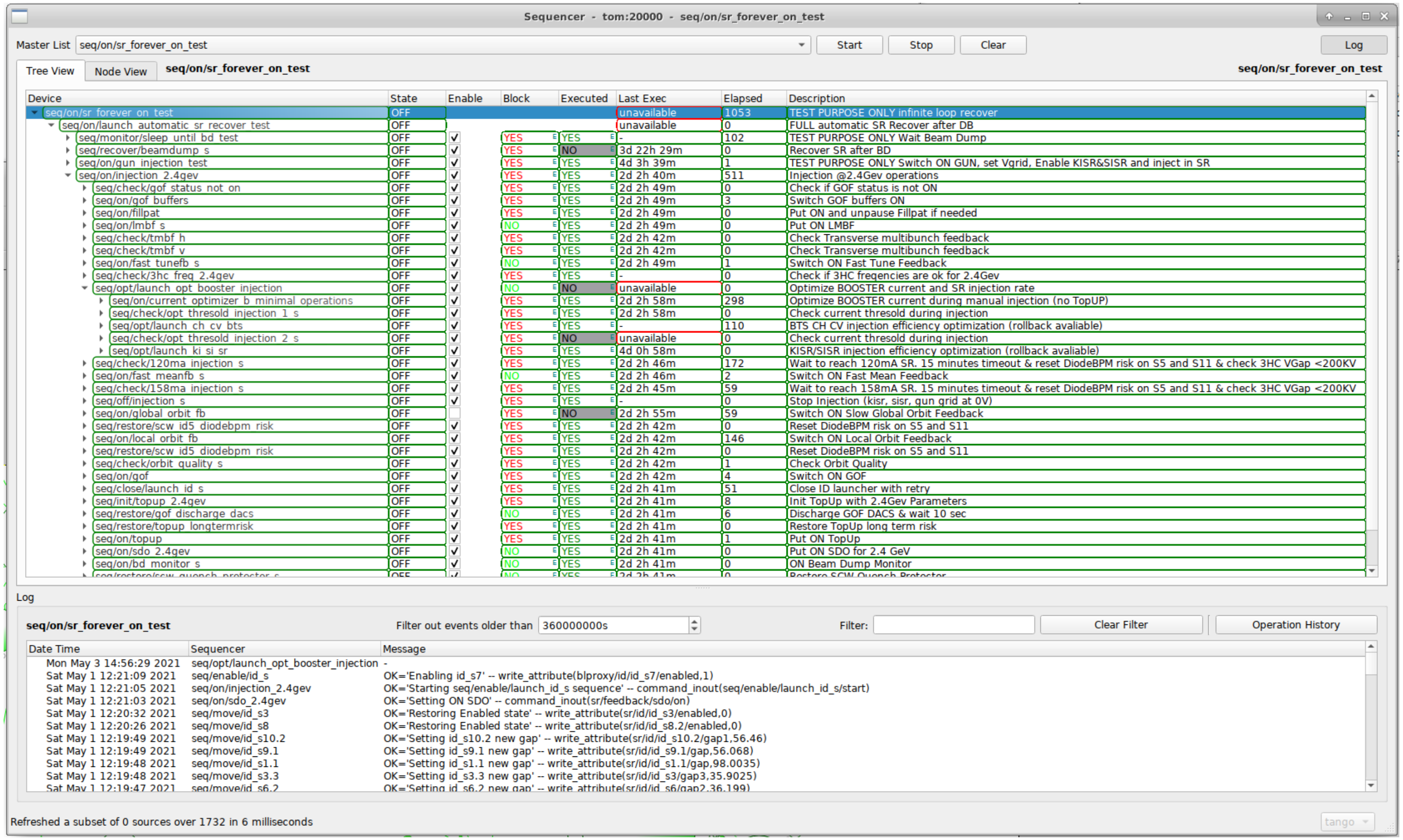
Injection- beam to user sequence



Recover from beam-loss sequence

Sequencers monitoring

Qt-based dynamic panel explores and monitors the execution of sequences (web interface available)



- ✓ Next steps:
  - Integration of *scikit-learn* and *OpenAI Gym* (optimizers)
  - Analyze drifts in the execution time to detect anomalies
  - Add BT learning capabilities to achieve more flexibility

Thank you!

N. Bruchon, P. Cinquegrana, G. Gaio, S. Krecic, G. Scalamera, G. Strangolino, F. Tripaldi, M. Trovo', L. Zambon