

# Automation, performance optimisation & ML @ Elettra G. Gaio

www.elettra.eu



#### 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

laser source TT1 Screen/CCD1 Screen/CCD2  $I_0$  monitor modulator light  $e^-$  beam  $e^-$  beam

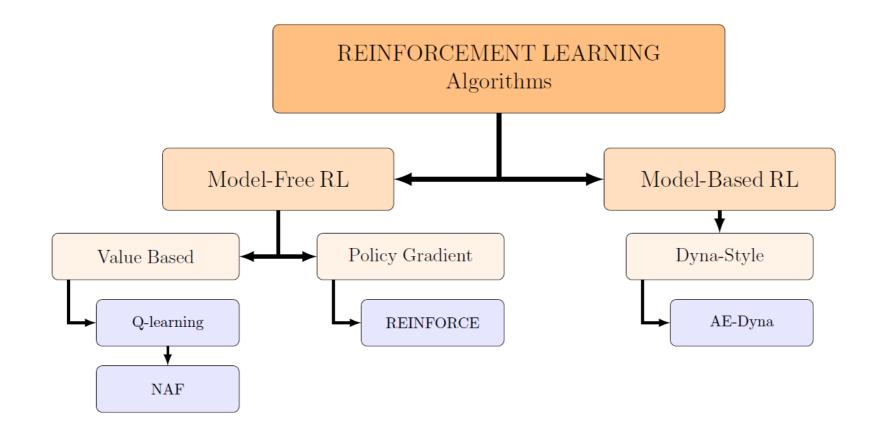
#### **Optimization of 4 variables**

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)

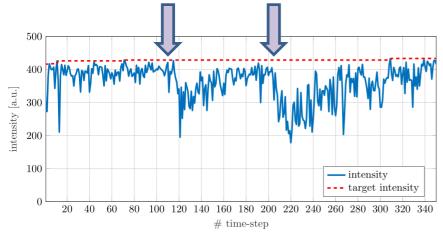


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### **Reinforcement Learning results**

#### 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		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
Not RL –	GradAscent	1024	3.82	0.9911
	iLQR	1024	2.54	1.0019





- 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 selfcontained tasks, regardless how they are implemented
- ✓ The tree-structure is composed by:
  - o a root node
  - o intermediate nodes (composite, selector, decorator) that control the flow
  - $\circ$  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

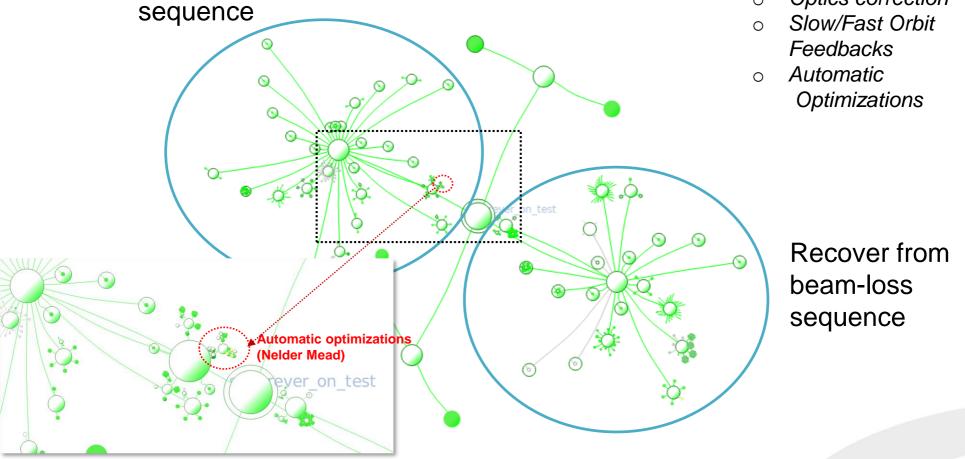




#### Elettra full automation



- ✓ Injection, beam to users
- ✓ It manages:
  - *HW devices*
  - Optics correction





Injection- beam to user



#### Sequencers monitoring

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

r List se	q/on/sr_forever_on_test							✓ Start Stop Clear	Lo
View	Node View seq/on/sr_forever_on_test							seq/on/sr_for	rever_or
ice		State	Enable	Block	Executed	Last Exec	Elapsed	Description	
sea/on/sr	r forever on test	OFF				unavailable	1053	TEST PURPOSE ONLY infinite loop recover	
	n/launch automatic sr recover test	<b>Î</b> OFF				unavailable	0	FULL automatic SR Recover after DB	
	q/monitor/sleep until bd test	OFF	$\checkmark$	YES	YES		102	TEST PURPOSE ONLY Wait Beam Dump	
	q/recover/beamdump s	OFF	✓	YES	E NO	3d 22h 29m	_ <u>[0</u>	Kecover SR after BD	
	q/on/gun injection test	<b>Į</b> OFF	_ <b>v</b>	YES		€ <mark>4d 3h 39m</mark>	1	TEST PURPOSE ONLY Switch ON GUN, set Vgrid, Enable KISR&SISR and inject in SR	
	q/on/injection 2.4gev	OFF	V .	YES		2d 2h 40m	511	Injection @2.4Gev operations	
	(seq/check/gof status not on (seq/on/gof buffers	OFF		YES		2d 2h 49m 2d 2h 49m	<u>_0</u>	Check if GOF status is not ON Switch GOF buffers ON	
	(seq/on/gor burrers (seq/on/fillpat	OFF		YES		2d 2h 49m 2d 2h 49m	10	Put ON and unpause Fillpat if needed	
	(seq/on/Impac	OFF		NO		2d 2h 49m	10	Put ON LMBF	
	(seq/check/tmbf h	OFF	- V	YES		2d 2h 49m	10	Check Transverse multibunch feedback	
	(seq/check/tmbf v	OFF	- İ	YES		2d 2h 42m		Check Transverse multibunch feedback	
	seq/on/fast tunefb s	OFF	V	NO		2d 2h 49m	Ť	Switch ON Fast Tune Feedback	
	seg/check/3hc freg 2.4gev	OFF	v	YES	YES	í-	10	Check if 3HC freqencies are ok for 2.4Gev	
	seq/opt/launch opt booster injection	ÎOFF	<b>v</b>	NO	E NO	unavailable	ĵo	Optimize BOOSTER current and SR injection rate	
	seq/on/current optimizer b minimal operations	OFF	✓	YES	E YES	2d 2h 58m	298	Optimize BOOSTER current during manual injection (no TopUP)	
	seq/check/opt thresold injection 1 s	OFF	✓	YES	E YES	2d 2h 58m	jo	Check current thresold during injection	
	seq/opt/launch ch cv bts	OFF	V	YES	• YES	4-	110	BTS CH CV injection efficiency optimization (rollback avaliable)	
	seq/check/opt thresold injection 2 s	OFF	<b>∨</b>	YES	E NO	unavailable	0	Check current thresold during injection	
	▶ (seq/opt/launch ki si sr	OFF	_ <b>v</b>	YES		🕻 4d 0h 58m	Îo	KISR/SISR injection efficiency optimization (rollback available)	
	(seq/check/120ma injection s	OFF		YES		2d 2h 46m	172	Wait to reach 120mA SR. 15 minutes timeout & reset DiodeBPM risk on S5 and S11 & check 3HC VGap	) <200K
	(seq/on/fast_meanfb_s	OFF		NO		2d 2h 46m	2	Switch ON Fast Mean Feedback	
	(seq/check/158ma injection s (seq/off/injection s	OFF		YES	E YES	2d 2h 45m	59	[Wait to reach 158mA SR. 15 minutes timeout & reset DiodeBPM risk on S5 and S11 & check 3HC VGap [Stop Injection (kisr, sisr, gun grid at OV)	<200K
	(seq/on/injection s (seq/on/global orbit fb	OFF		YES	E NO	2d 2h 55m	59	Switch ON Slow Global Orbit Feedback	-
	seq/restore/scw id5 diodebpm risk	OFF		YES		2d 2h 33m	139	Reset DiodeBPM risk on S5 and S11	
	(seq/nestore/scw las alogeophi lisk	OFF	- ÷	YES		2d 2h 42m	146	Switch ON Local Orbit Feedback	
	seq/restore/scw id5 diodebpm risk	IOFF		YES		2d 2h 42m	10	Reset DiodeBPM risk on S5 and S11	
	seg/check/orbit guality s	IOFF	v	YES		2d 2h 42m	1	Check Orbit Quality	
•	seq/on/gof	OFF	<b>v</b>	YES		2d 2h 42m	4	Switch ON GOF	
+	seq/close/launch id s	OFF	V	YES	E YES	🖞 2d 2h 41m	<u>[</u> 51	Close ID launcher with retry	
	(seq/init/topup 2.4gev	OFF	✓	YES		🛿 2d 2h 41m	8	Init TopUp with 2.4Gev Parameters	
	seg/restore/gof_discharge_dacs	<b>Į</b> OFF	$\checkmark$	NO		2d 2h 41m	6	Discharge GOF DACS & wait 10 sec	
	seq/restore/topup longtermrisk	<b>Į</b> OFF	✓	YES		2d 2h 41m	<u>lo</u>	JRestore TopUp long term risk	
	(seq/on/topup	OFF		YES		2d 2h 41m	1	Put ON TopUp	
	seq/on/sdo 2.4gev	OFF	<u> </u>	NO		2d 2h 41m	10	Put ON SDO for 2.4 GeV	
	(seq/on/bd monitor s	[OFF	V .	NO	E YES	2d 2h 41m	0	ON Beam Dump Monitor	-
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	1 12:21:05 2021 seq/enable/id_s 1 12:21:05 2021 seq/on/injection 2.4gev							e/launch id s/start)	
	1 12:21:03 2021 seq/on/sdo 2.4gev					edback/sdo/on)	actocq/citable		
	1 12:20:32 2021 seq/move/id s3					te(sr/id/id s3/enable	ed.0)		
	1 12:20:26 2021 seq/move/id s8	OK='Rest	oring Enable	ed state'	write attribut	te(sr/id/id_s8.2/enal	bled,0)		
	1 12:19:49 2021 seq/move/id_s10.2	OK='Setti	ing id_s10.2	new gap'	write_attrib	ute(sr/id/id_s10.2/g	gap1,56.46)		
	1 12:19:49 2021 seq/move/id_s9.1	OK='Setti	ing id_s9.1 r	new gap' -	<ul> <li>write_attribu</li> </ul>	te(sr/id/id_s9.1/gap	,56.068)		
Sat May	1 12:19:48 2021 seq/move/id_s1.1	OK='Setti	ing id s1.1 r	new gap' -	- write_attribu	te(sr/id/id_s1.1/gap	,98.0035)		
	1 12:19:48 2021 seq/move/id_s3.3					te(sr/id/id_s3/gap3,			
Sat May	1 12:19:47 2021 sea/move/id_s6.2	OK='Setti	ina id s6.2 r	new dap' -	- write attribu	te(sr/id/id_s6/gap2	.36.199)		

- ✓ Next steps:
  - Integration of *scikit-learn* and *OpenAI Gym* (optimizers)
  - $\circ$   $\,$  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



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Giulio Gaio, 11/05/2021

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