Elettra
Sincrotrone
Trieste

A FRAMEWORK FOR HIGH LEVEL MACHINE AUTOMATION BASED ON BEHAVIOR TREES

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on behalf the Sequencer TEAM

www.elettra.eu

Elettra Sincrotrone Trieste

Introduction

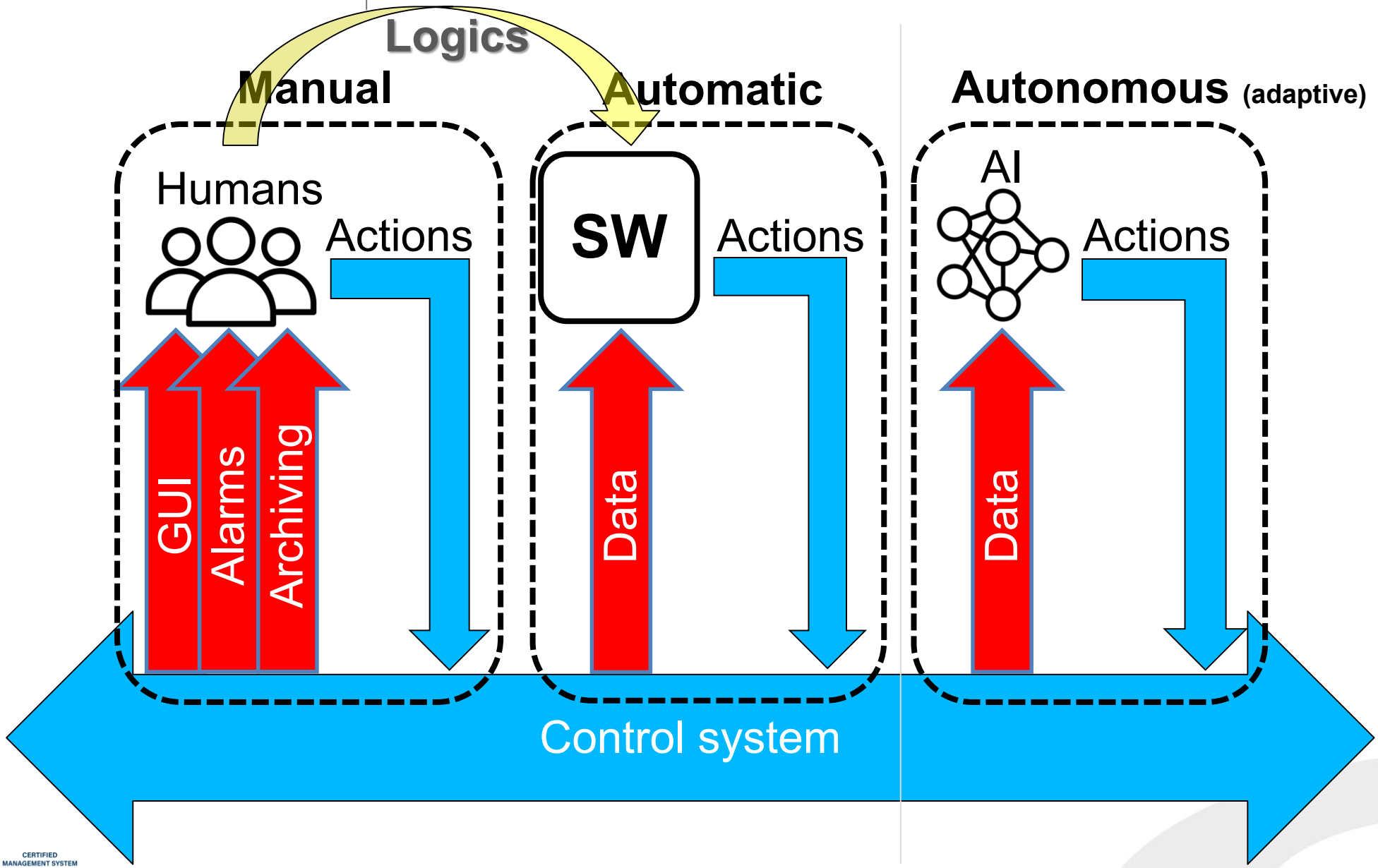
✓ Automation frameworks:

- *The Colliding Beam Sequencer (FNAL - PAC89)*
- *Automating ELETTRA Operation with One Button Machine (Elettra - IPAC97)*
- *The RIHC Sequencer (BNL - PAC01)*
- *A sequencer for LHC ERA (CERN - ICALEPCS09)*
- *Automated operation of ITER using behavior tree semantics (ITER – this conference **WEPV006**)*
- ……
- EPICS sequencer
- …….

SOLEIL, DESY....and many many others

Sorry if I haven't mentioned your work!

Toward full automation



Automation metric

- ✓ For a user facility like a synchrotron **full automation** means:
  - Recover from a beamdump, reinject and give a stable beam to the users without any human intervention
- ✓ A metric to measure human intervention is:
  - ***Quantum of human-computer interaction (Qhci)****:* one click on a keyboard/mouse in the control room during user and machine tuning shifts

$$\mathbf{AL(U)} = \Sigma\,[Q_{hci(U)}]_{\text{per day}}$$
$$\mathbf{AL(T)} = \Sigma\,[Q_{hci(T)}]_{\text{per day}}$$

Automation **L**evel = AL(U) + AL(T)

AL = 0 autonomous machine

Scripting language

- ✓ Move logics from GUIs and stand alone scripts to server side applications (tango servers)
- ✓ Speed up the knowledge transfer by involving more people
- ✓ Minimize bugs by privileging configuration instead of programming
- ✓ **Home-made scripting language** (based on C++ Boost.Spirit parser)
  - Implement IF/ELSE (conditional ternary operator "? :") and the "harmful" GOTO statements

Language syntax

stepN;[expression];[step description];[error message];[timeout ms.];[catch exceptions]

Sequence example (reset and turn ON a power supply):

step1;read(sr/ps/ch_s1.1/State)==FAULT **?** command(sr/ps/ch_s1.1/Reset) && **goto(2) : goto(3)**;Reset PS;Error resetting PS;3000
step2;read(sr/ps/ch_s1.1/State) != OFF **?** sleep(1) && **goto(2) : goto(3)**;Waiting OFF state;Timeout waiting OFF state;6000
step3;read(sr/ps/ch_s1.1/State) != ON **?** command(sr/ps/ch_s1.1/On) && **goto(4) : goto(5)**;Turn PS ON;Error turning ON PS;3000
step4;read(sr/ps/ch_s1.1/State) != ON **?** sleep(1) && **goto(4)** : **goto(5)**;Waiting ON state;Timeout waiting ON state;6000

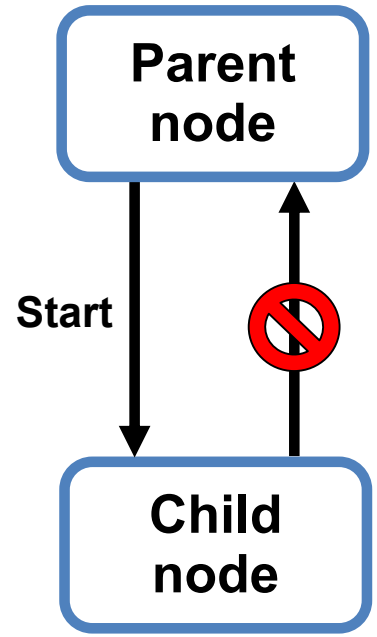
Description:

step1; If PS is in FAULT state then Reset and **go to step2**, otherwise **go to step3**
step2; if PS is not OFF then sleep one sec and check again (max 6 sec.), otherwise **goto step3**
step3; if PS is not ON turn PS ON and **go to step4**, otherwise **go to step5** (exit)
step4;if PS is not ON then sleep one sec and check again (max 6 sec.), otherwise **go to step5** (exit)

Behavior Trees

✓ **Used by AI in video games (Unreal Engine), UAV…**

Direct Acyclic Graph



Node states
SUCCESS
RUNNING
FAULT

The **parent node starts** the execution of the **child node** and **waits** it to complete the task. If the **child node** goes in **FAULT** state then also the **parent node** will end in **FAULT** state.

Structural nodes:

sequence, composer, fallback, selector, decorator

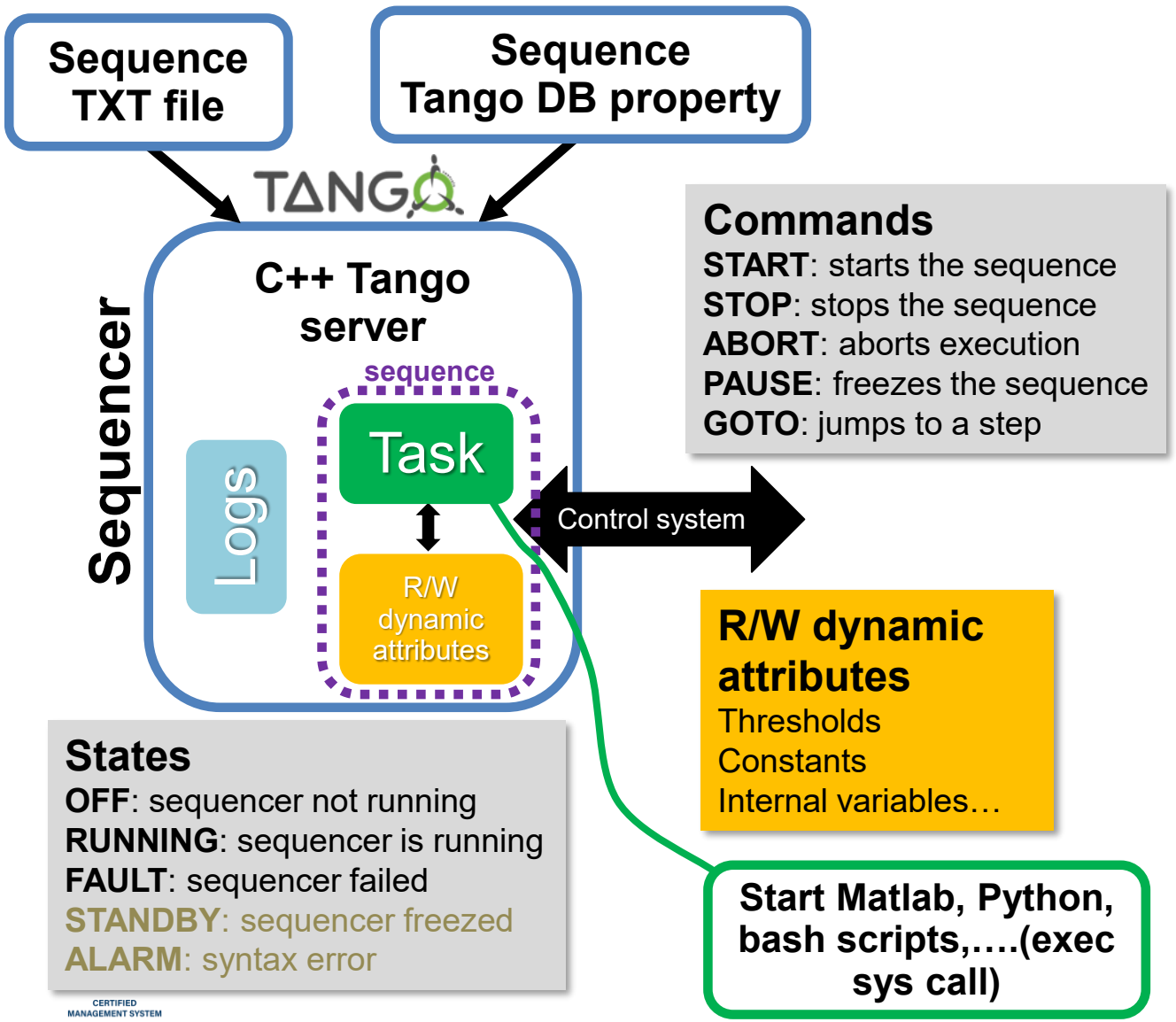
A node executes **a real action** or implements **the structure of the BT:**

- start child nodes in series
- start child nodes in parallel
- invert the returning state of a child node
- Execute at least one child node from a multitude
- Conditional execution between two child nodes
- …….

All nodes are implemented with the scripting language

Tree node: the Sequencer

The Sequencer is a Tango device implementing a task

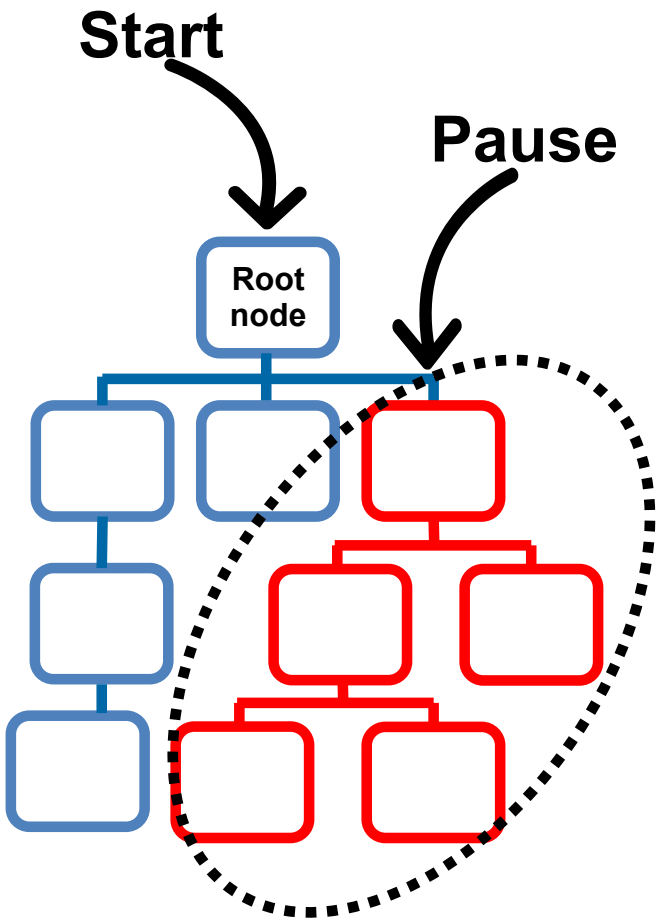


Commands
START: starts the sequence
STOP: stops the sequence
ABORT: aborts execution
PAUSE: freezes the sequence
GOTO: jumps to a step

R/W dynamic attributes
Thresholds
Constants
Internal variables…

States
OFF: sequencer not running
RUNNING: sequencer is running
FAULT: sequencer failed
STANDBY: sequencer freezed
ALARM: syntax error

Start Matlab, Python, bash scripts,….(exec sys call)



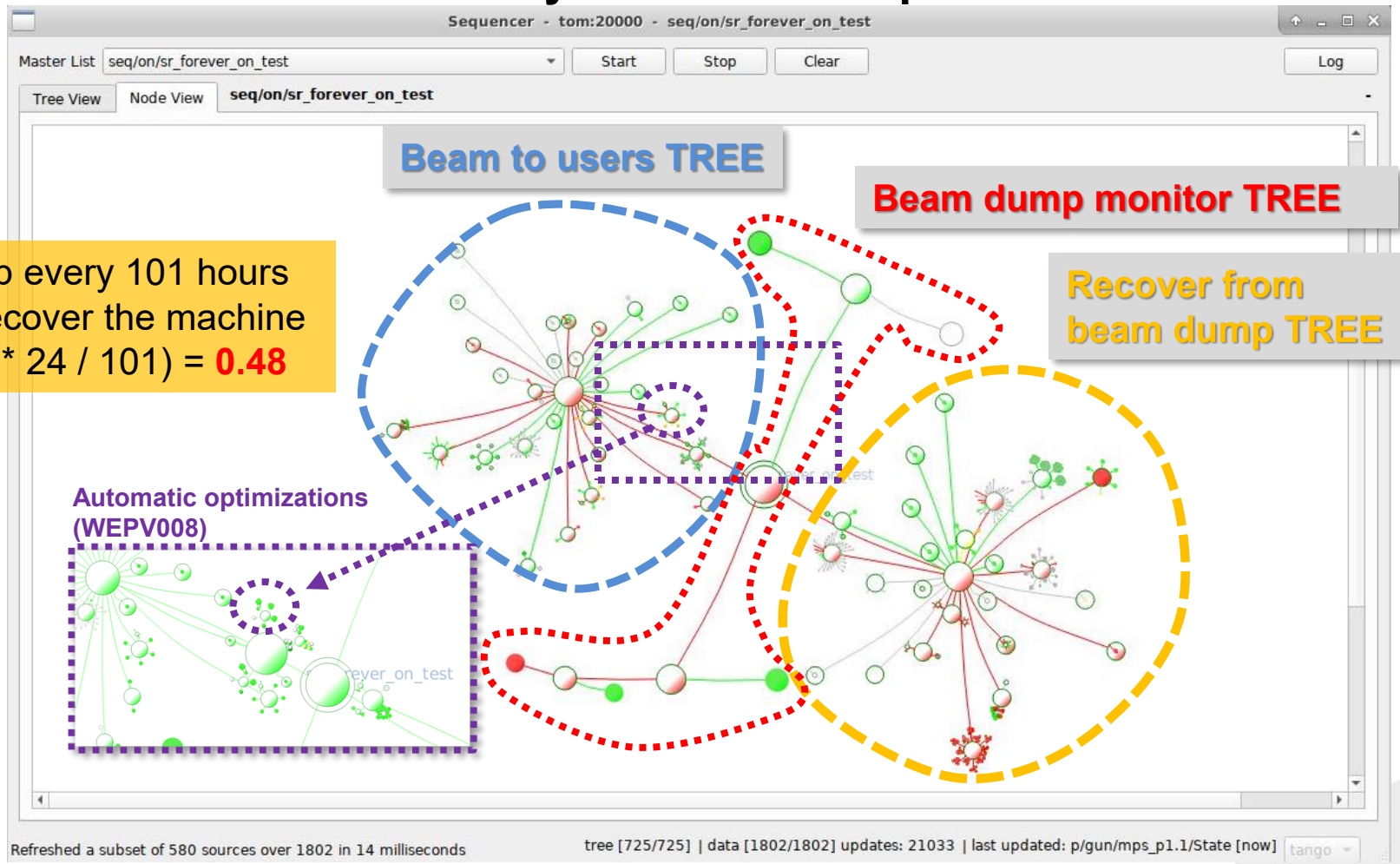
Can propagate **Stop**, **Abort** and **Pause** command through a sub-tree

Sequencer GUI (Node view)

All grafical interfaces (Qt-Cumbia) are automatically generated by getting information from the Tango Database and by dynamically exploring the Behavior Tree.

Elettra synchrotron autopilot

1 beamdump every 101 hours
2 clicks to recover the machine
AL(U) >= (2 * 24 / 101) = **0.48**



725 nodes **1802 attributes**

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Sequencer GUI (Tree View)

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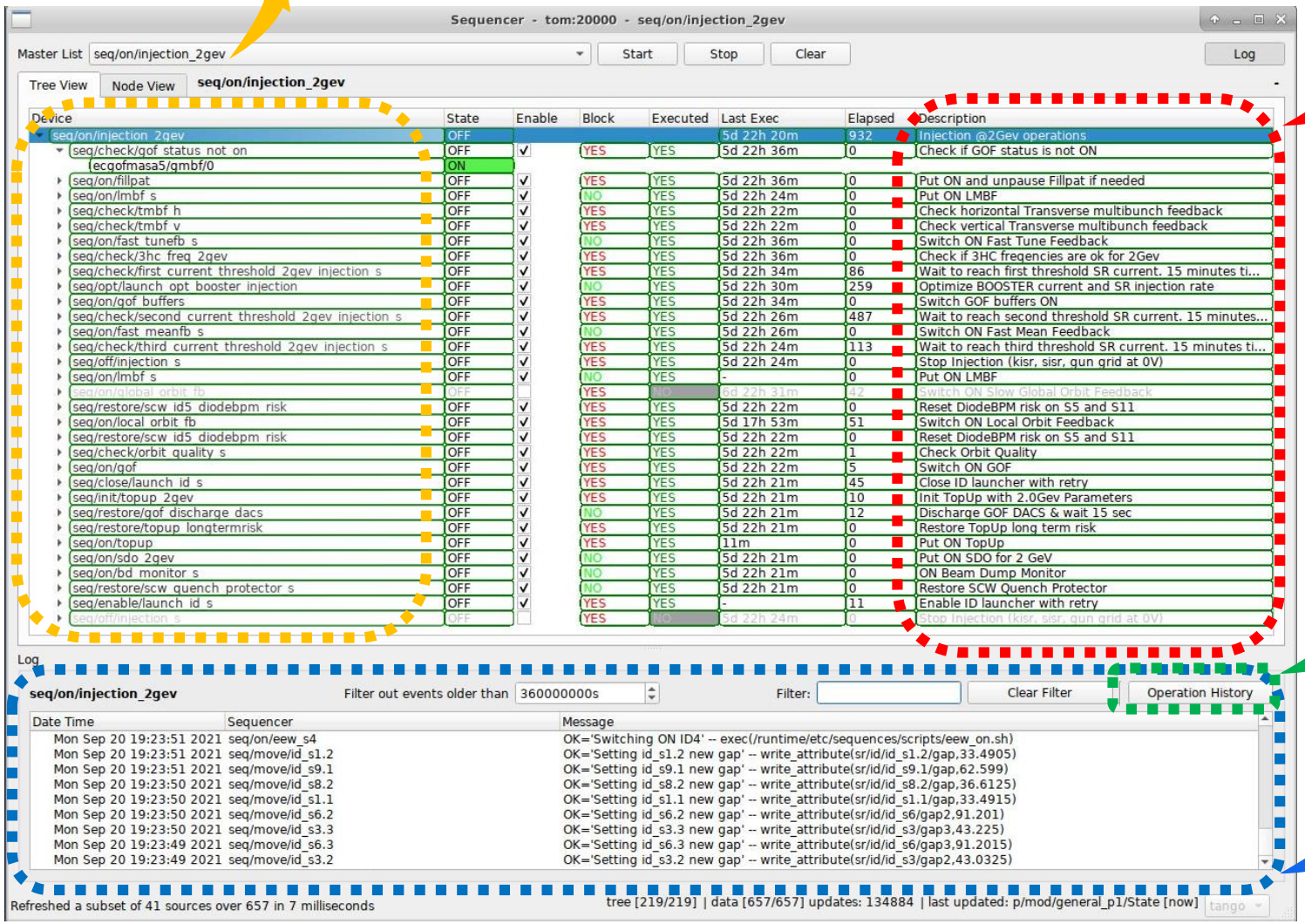
Sequencer that refills the storage ring till giving stable beam to the users



Sequence description

Historical logging

RT-logging based on events

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20/10/2021

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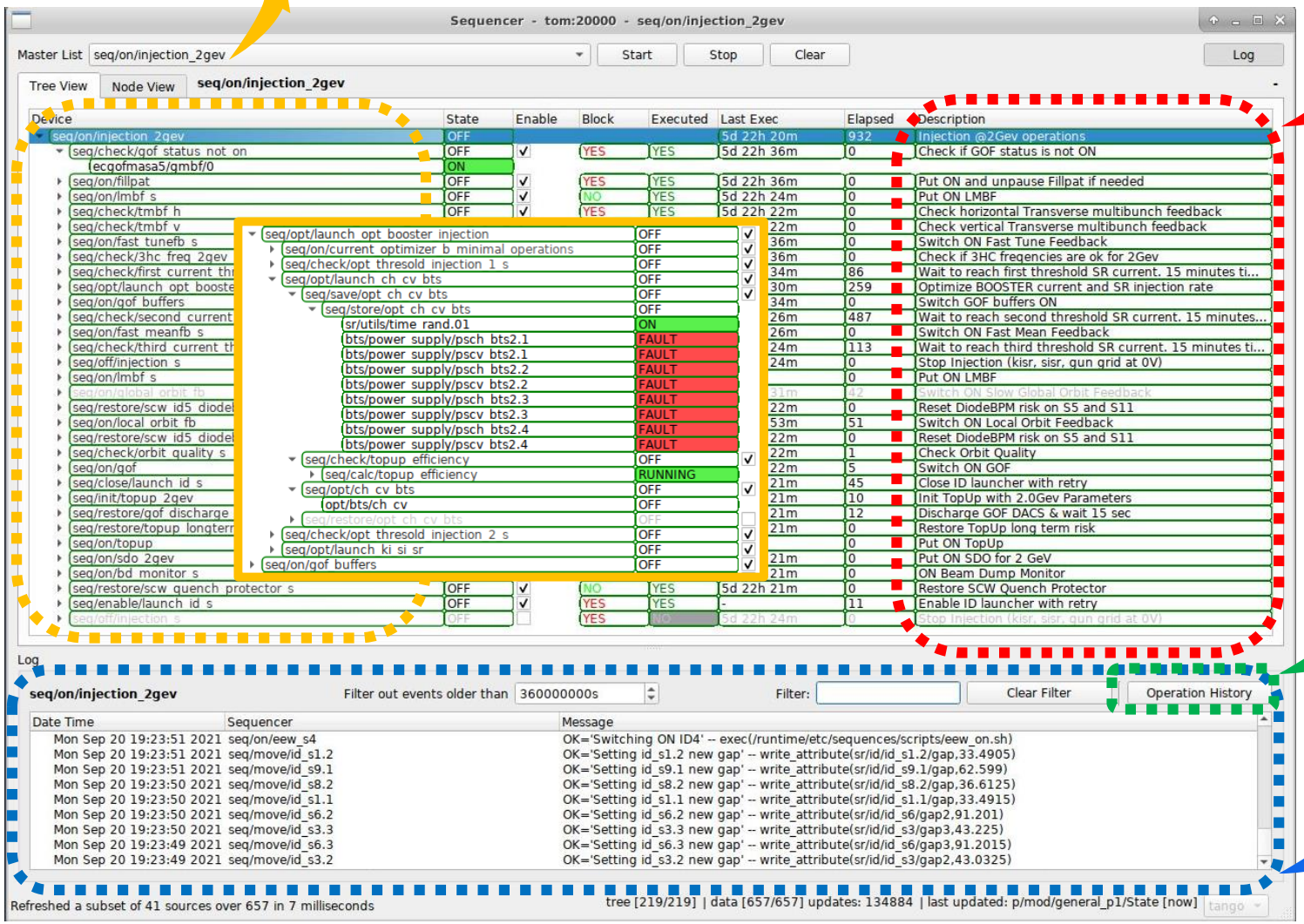

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Conclusions

- ✓ 995 sequencers in FERMI, 958 sequencers in Elettra
- ✓ 8 people have been involved (Controls + Operators + Physicists), now 1 FTE
- ✓ In operation in Elettra since 2019, almost all high level operations in control room driven by sequencers
- ✓ Introduced in FERMI in 2021
- ✓ Developer doesn't have to care of GUIs, logging, documentation…all out of the box
- ✓ "Framework" based on one C++ Tango server, two Qt-Cumbia panels and a sequence template that eases the implementation of the BT structure
- ✓ Short term to-do list:
  - Versioning of an entire BT logic (md5)
  - Log analysis to detect anomalies in terms of execution time and fault rate

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Thank you!

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