# COMPASS iFDAQ Software

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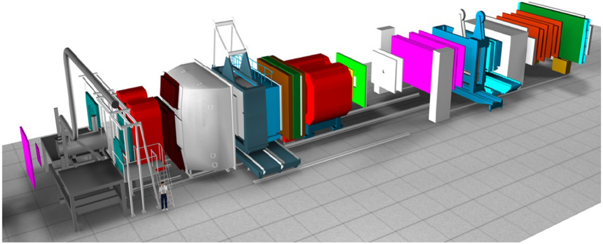
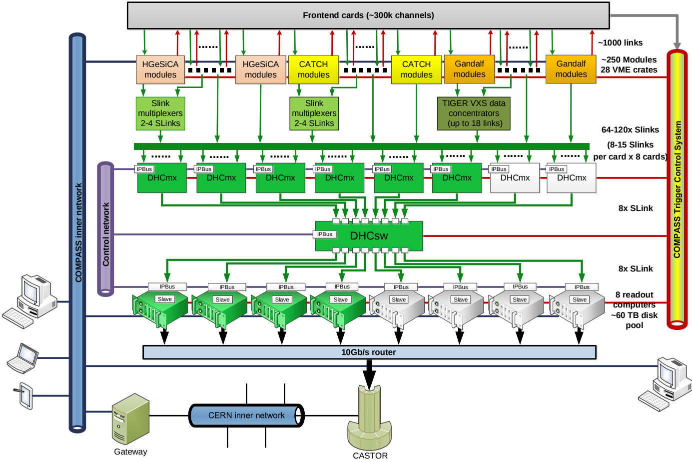
# COMPASS experiment

- Fixed target experiment at SPS accelerator at CERN
- Study of hadron structure and hadron spectroscopy with high intensity muon and hadron beams
- Data-taking started in 2002
- Trigger rate up to 50 kHz, average event size up to 50 kB (not at the same time)
- In spill data rate 1.5 GB/s and sustained data rate 500 MB/s



# Hardware Structure

- Hardware based E.B.
- Data concentrated by 6 (up to 8) DAQ modules with multiplexer firmware
- Distribution to 4 (up to 8) readout computers by DAQ module switch firmware
- Full events received by servers
- Consistency check at many layers
- Events checked and transferred to DATE data format
- Easy to add new data source

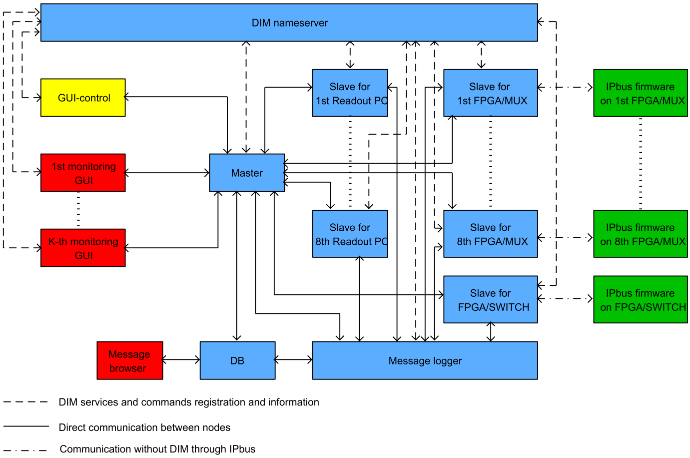


# Used Software Technologies

- C++, Python
- Qt framework
- DIM (Distributed Information Management System)
- DIALOG library
- IPbus suite for communication with FPGA cards
- MySQL
- PHP, JavaScript
- Zabbix

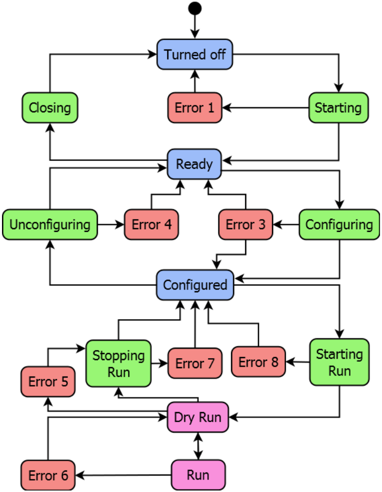
# Software Structure

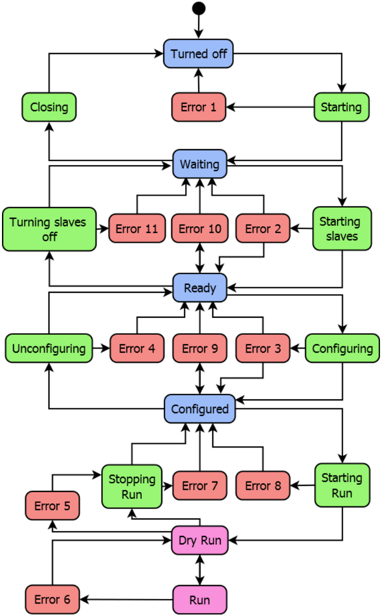
- Runcontrol GUI is a graphical user interface
- Master is a main control process
- Slave-readout readouts and verifies the data
- Slave-control monitors and controls the FPGA cards
- MessageLogger stores informative and error messages into the database
- MessageBrowser provides an intuitive access to messages stored in the database



# State machine

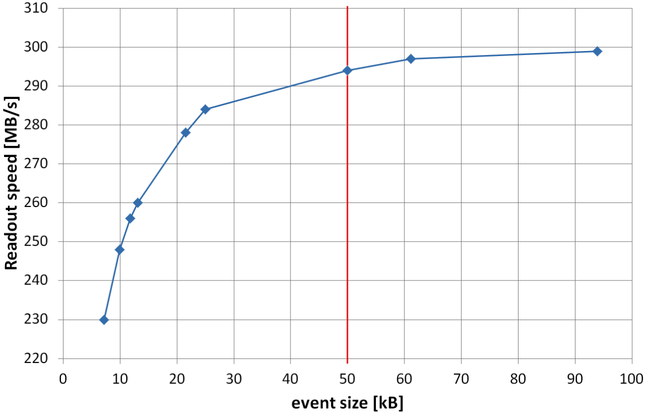
- Well defined states - system with self-repair capability



# Maximum Data Readout Performance

- Currently limited by SWITCH firmware to 100 MB/s per RE if 4 RE connected
- If 2 RE connected to not-shared ports, readout speed of up to 150 MB/s per RE, $\leq$12 % CPU usage



# DIM I – Distributed Information Management System

- Developed at CERN in 1993, still with support
- Design requirements
    - Efficient communication mechanism – asynchronous behavior, sending and receiving asap
    - Uniformity – all processes use the same communication mechanism
    - Transparency – any running process should be able to communicate with any other process
    - Reliability and robustness – system recovery in a self-recoverable manner from error situations
- It uses UDP protocol for message transmission

# DIM II – Usage in iFDAQ

- Fully incorporated to all processes for the runs 2014 and 2015
- DIM problems
  - Occasional message truncation or complete loss of the message
  - As a consequence of that, processes crashed without any obvious reason (especially Master process)
- DIM library replaced by DIALOG library
- DIM library can not be completely avoided (still partially present)
  - VME computers have only 64 MB memory $\rightarrow$ we can not install Qt framework there
  - DIALOG library is implemented in Qt framework

# DIALOG Library I

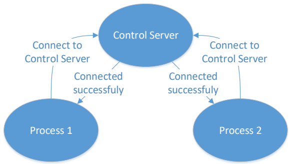
- Replacement of DIM Library
- It is implemented in Qt framework
- Dialog means conversation, talk or speech (**D** – distributed, **I** – inter-process, **A** – asynchronous, **L** – library, **O** – open, **G** – general)
- Design requirements similar to DIM Library
- Communication based on the publish/subscribe method
- It uses TCP/IP protocol for message transmission

# DIALOG Library II

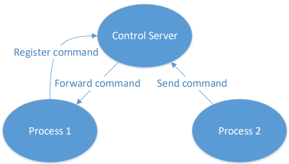
- Services
  - A service is a set of data of any type and size with an unique name
  - Server/Client mechanism – server publishes data to several clients
- Commands
  - Process registers command with a non-unique name it is willing to accept
  - One process can control another one via command
- Implementation
  - The Control Server – keeping an up-to-date list of all the processes, services and commands
  - Providers – a process providing services and commands it is willing to accept
  - Subscribers – a process specifying the service name it is interested in and requesting for it
  - Any process can be a provider and a subscriber at the same time

# DIALOG Library III - Scenarios

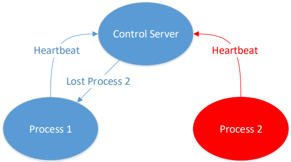
## Connection to the Control Server



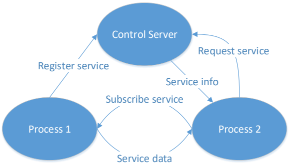

## Commands



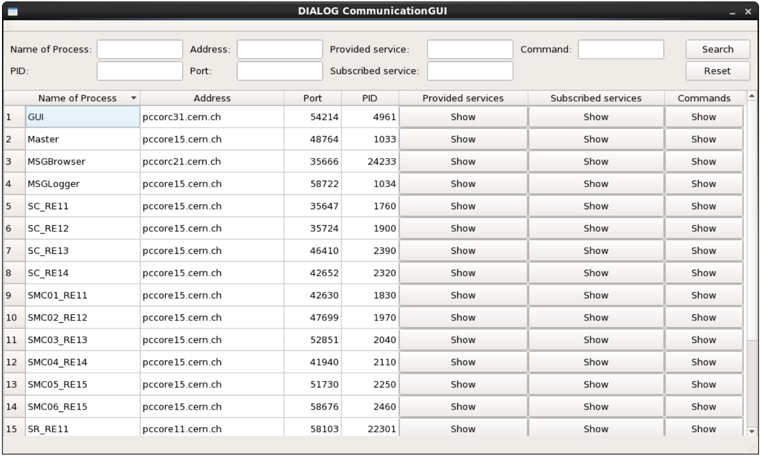

## Heartbeats




## Services



# DIALOG Online Monitoring

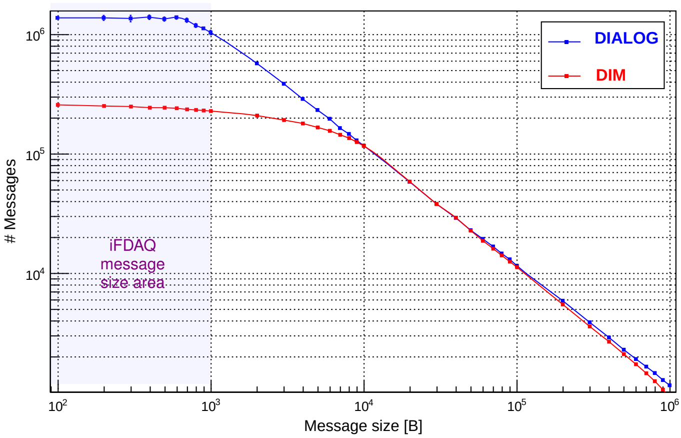



| | Name of Process | Address | Port | PID | Provided services | Subscribed services | Commands |
|---|---|---|---|---|---|---|---|
| 1 | GUI | pccorc31.cern.ch | 54214 | 4961 | Show | Show | Show |
| 2 | Master | pccore15.cern.ch | 48764 | 1033 | Show | Show | Show |
| 3 | MSGBrowser | pccorc21.cern.ch | 35666 | 24233 | Show | Show | Show |
| 4 | MSGLogger | pccore15.cern.ch | 58722 | 1034 | Show | Show | Show |
| 5 | SC_RE11 | pccore15.cern.ch | 35647 | 1760 | Show | Show | Show |
| 6 | SC_RE12 | pccore15.cern.ch | 35724 | 1900 | Show | Show | Show |
| 7 | SC_RE13 | pccore15.cern.ch | 46410 | 2390 | Show | Show | Show |
| 8 | SC_RE14 | pccore15.cern.ch | 42652 | 2320 | Show | Show | Show |
| 9 | SMC01_RE11 | pccore15.cern.ch | 42630 | 1830 | Show | Show | Show |
| 10 | SMC02_RE12 | pccore15.cern.ch | 47699 | 1970 | Show | Show | Show |
| 11 | SMC03_RE13 | pccore15.cern.ch | 52851 | 2040 | Show | Show | Show |
| 12 | SMC04_RE14 | pccore15.cern.ch | 41940 | 2110 | Show | Show | Show |
| 13 | SMC05_RE15 | pccore15.cern.ch | 51730 | 2250 | Show | Show | Show |
| 14 | SMC06_RE15 | pccore15.cern.ch | 58676 | 2460 | Show | Show | Show |
| 15 | SR_RE11 | pccore11.cern.ch | 58103 | 22301 | Show | Show | Show |

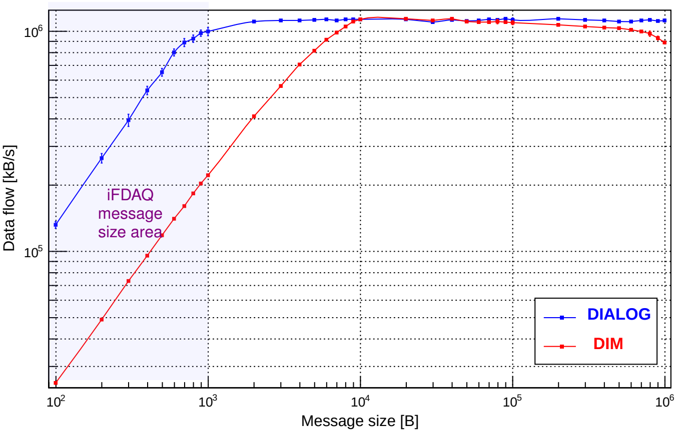
# Performance Test I – Test Setup

- DIALOG and DIM performance are measured and compared in two plots
  - Number of messages – how many messages can be delivered to one single process in 1 second
  - Data flow – how many bytes can be delivered to one single process in 1 second
- 25 slaves (17 slave-control, 8 slave-readout) send status to Master process → the iFDAQ full setup
- The test is conducted for different message sizes and for each message size is conducted five times to obtain the sufficient statistics
- The network bandwidth is 10 Gbps for the test
  - We can expect the maximum data rate $\sim$ 1.2 GB/s (throughput)
  - The network bandwidth is not saturated by anything else during test
- Correct spreading of slaves among machines
  - Message sent by process 1 to process 2 running on the same machine is sent directly and it is not going through the network at all
    - The test results would have been even above the network bandwidth

# Performance Test II – Number of Messages



# Performance Test III – Data Flow



# DAQ Debugger I

- Library for the iFDAQ error detection
- Fully incorporated to all processes during the run 2016 and 2017
- Design requirements
  - The integration to running system requires interface for an easy use
  - It does not affect the process performance
  - It does not increase load on readout engine computers
  - It provides with reports in `/tmp` folder containing stack trace of all threads and memory dump

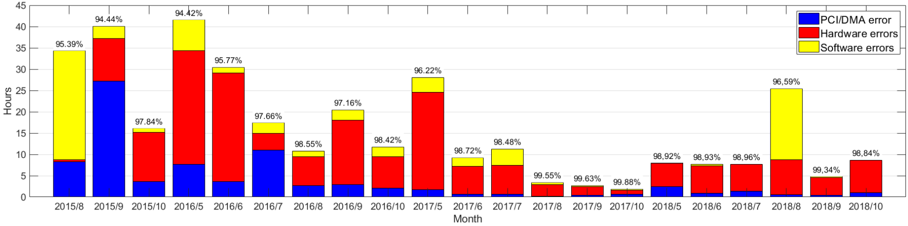
# DAQ Debugger II

- Main goal is to produce a report of the process crash
- Based on catching of system signals (SIGSEGV, SIGABRT, etc.)
    - The system signal is caught and forwarded to a signal handler in the DAQ Debugger
    - The memory dump is produced and stored
    - The whole stack trace for each thread is generated with file names and code line numbers
    - The report containing the caught signal and stack trace for each thread is created in `/tmp` folder
    - The process is exiting with the caught signal
- Reports are investigated by iFDAQ experts
- Problem understanding $\rightarrow$ the fix is released and tested

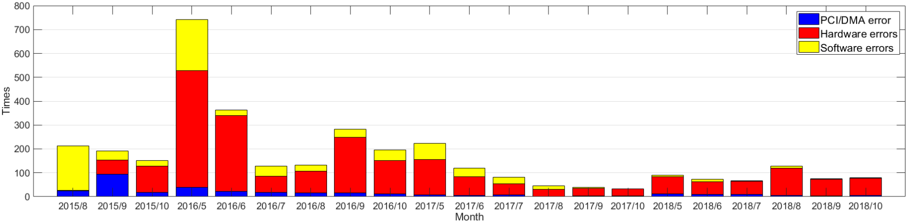
# DAQ Debugger III – Implementation

- `DAQDebugger::init(processName)` to initialize
- Crash procedure
  - The system signal is caught in the crashed thread
  - All remaining threads are immediately suspended
  - Store memory dump
  - Get stack trace of the crashed thread
  - Get stack traces of suspended threads
  - The crashed thread (whole process) is exiting with the caught signal
- Using POSIX defining a standard threading library API (suspend/resume signals)
- Using `backtrace`, `backtrace_symbols` and `addr2line` to create a report
- Using `gcore` for memory dump storage

# iFDAQ Stability




Error hours per month




Error count per month

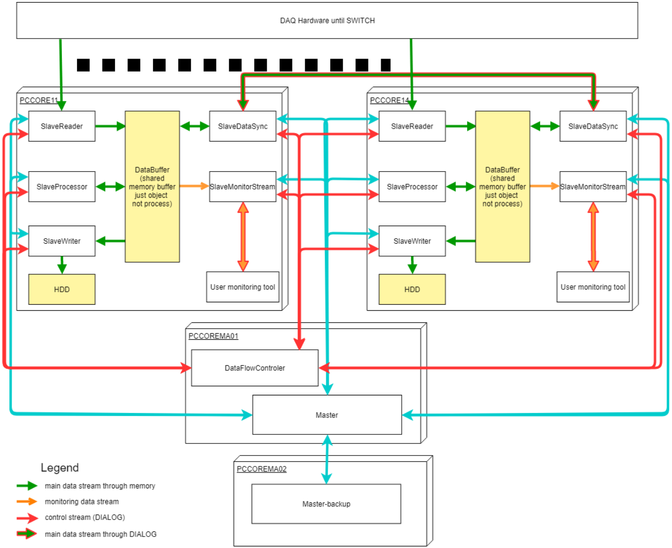
## Present features

- Continuously running DAQ
- Deployment tool
- API
- Text User Interface
- Integrated logbook
- Web-based checklist

## Future development

- Load distribution
- Process redundancy
- "Space" for analysis and checks
- Data quality assessment
- Software event building

- Fragmentation of main readout process to several sub-processes
- Intelligent scheduling
- Filtration/High level trigger possibilities
- Software event building
- Data sharing
- Configurable storage



# Conclusion

- Own communication library DIALOG
- Internal DAQ Debugger
- iFDAQ UpTime is around 99%
- TUI - for scripting
- Easy to operate, but possible to tune by experts
- possible extension for higher rates and software event building
- Team of skillful developers created - 1x Postdoc, 3x PhD, 2x Master, 2x Bachelor students

# The End

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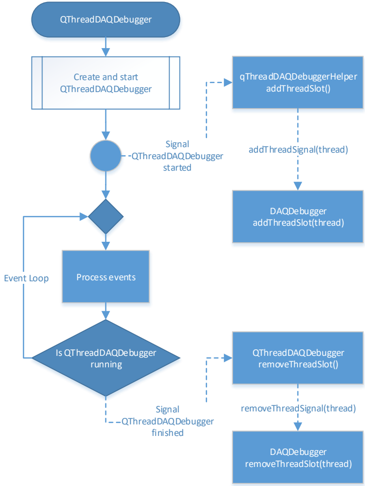
# DAQ Debugger IV – Thread Life Cycle

- The `QThreadDAQDebugger` object inheriting from `QThread` object
- To control thread via POSIX, thread ID is necessary to obtain using `QThreadDAQDebuggerHelper`
- Registration of thread in DAQ Debbugger by `addThreadSlot(thread)` method
- Standard thread execution with processing of events until the thread finishes
- `QThreadDAQDebugger` object finishes its execution
- Unregistration of thread in DAQ Debugger by `removeThreadSlot(thread)` method
- For simplicity reasons, the thread crash is not depicted in the diagram



# DAQ Debugger V – Before Process Crash

- DAQ Debugger is a part of a process and standing in the background of a running process
- A process is running smoothly $\rightarrow$ the DAQ Debugger does not take any action $\rightarrow$ no effect on the process performance and no load increase on readout engines
- The system signals are registered, the process continues its execution
- Once the crash of process occurs, the DAQ Debugger handles it

# DAQ Debugger VI – Process Crash

- Process crash $\rightarrow$ the system signal is emitted
- It is caught by the signal handler of crashed thread in the DAQ Debugger
- The crashed thread sends the suspend signal to all remaining threads
- The memory dump is produced and stored
- The report file is created and open for writing
- The crashed thread writes its stack trace to the file

# DAQ Debugger VI – Process Crash

- The crashed thread sends the resume signal to first suspended thread and the crashed thread itself is suspended
- The resumed thread writes its stack trace to the file, then sends the resume signal to the crashed thread and is suspended again
- The resumed crashed thread sends the resume signal to second thread and it is again suspended
- The second resumed thread writes its stack trace to the file, then sends the resume signal to the crashed thread and is suspended again

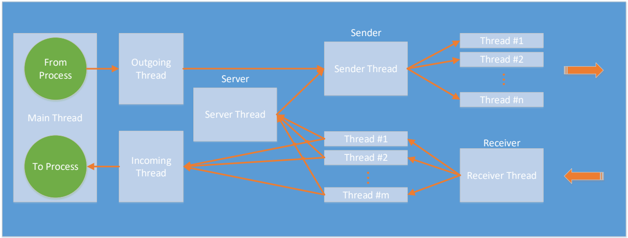
# DAQ Debugger VI – Process Crash

- It continues in this way to the last suspended thread
- The resumed crashed thread (resumed by the resume signal sent from $(n-1)$-th thread) sends the resume signal to $n$-th thread and it is again suspended
- The $n$-th resumed thread writes its stack trace to the file, then sends the resume signal to the crashed thread and is suspended again
- This suspend/resume procedure ensures the serial writing to file and proper thread control
- The report file is closed and process is exiting with the caught signal in the crashed thread

# DIALOG Library IV - Process Threads

- Message types are distinguished by message header
- The Sender dispatches messages among $n \in \mathbb{N}$ threads
- $n \in \mathbb{N}$ threads are establishing connections to other processes, writing data to sockets and keeping sockets open until timeout
- Open socket, pointers to messages, sending as soon as possible $\rightarrow$ speed up the performance and reduce the latency significantly
- The Receiver dispatches a new socket descriptor to one of $m \in \mathbb{N}$ threads
- $m \in \mathbb{N}$ threads are responsible for reading data out from sockets
- The sockets are kept open until they are closed by sender process

Process



# DIALOG Library V - from Process 1 to Process 2

- If the connection is not yet established, the object socket is created and opened in Process 1
- The Receiver receives the socket descriptor trying to connect to Process 2
- Socket objects exist on both sides till timeout, process crash or process termination
- The open socket is used only for one direction connection