The new inter process communication middle-ware for the ATLAS Trigger and Data Acquisition system

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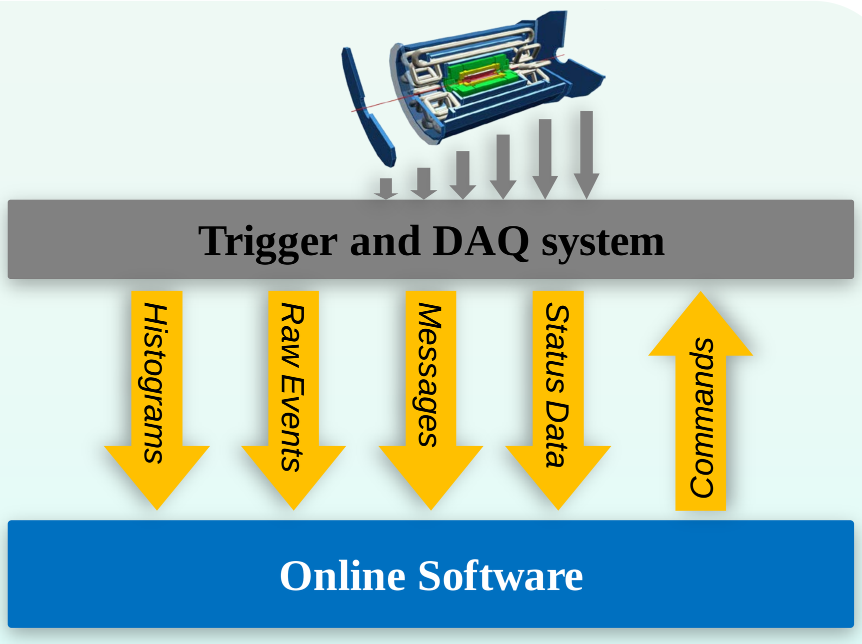
1. The ATLAS TDAQ Online Software

The ATLAS Trigger & Data Acquisition (TDAQ) project started almost twenty years ago with the aim of providing a scalable distributed data collection system for the experiment. While the software dealing with physics data flow was implemented by directly using low-level communication protocols, like TCP and UDP, the control and monitoring infrastructure services for the TDAQ system were implemented on top of the CORBA communication middle-ware.



The ATLAS TDAQ Online Software places very demanding requirements on the Inter-Process Communication (IPC) system:

- The Online Software has to control and monitor the TDAQ system, which is composed of O(10)K processes distributed over O(1)K computers, connected via high-speed LAN
- All components of the TDAQ system have to be operated with quasi-realtime performance as this is crucial for maximizing the efficiency of the experiment

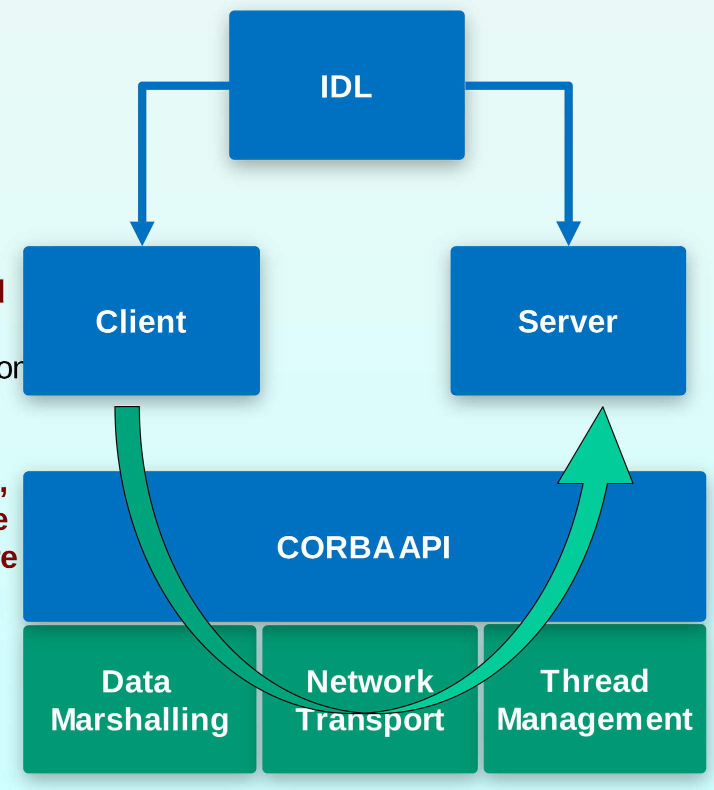
The first incarnation of the Online System, which was born in 1998, is based on the CORBA communication middleware. Two CORBA implementations have been used: **JacORB** for Java and **omniORB** for C++. They both satisfied the performance and scalability requirements and simplified development and maintenance of the Online Software.

However after more than 10 years successful experience with the CORBA brokers, we have decided the time is right to explore if there are new products on the IPC software market, which can improve our system performance and maintainability.

2. CORBA in the modern software world

CORBA is an open standard for distributed object computing, which was proposed in 1991 by the Object Management Group (OMG). This was the first attempt to provide a broad high-level standard for information exchange in a distributed software environment, which was quite successful and played an important role in the overall evolution of distributed software systems.
However many key features of the CORBA standard have a number of built-in drawbacks, which have become more and more prominent in recent years, making CORBA less attractive for modern software development.

- CORBA defines the PL-neutral Interface Definition Language for communication protocol description. The code for a specific PL is generated from such a description.
  Mapping of IDL to different PLs (e.g. C++ and Java) is old-fashioned and inefficient as it does not support zero-copy data transfer.
- CORBA provides a high-level object-oriented API which hides all aspects of the communication implementation.
  This simplifies development but adds noticeable overhead and significantly reduces flexibility.
- CORBA standardizes an API for object creation, registration, location and activation, thus assuring source code compatibility between different CORBA implementations.
  This model is quite complex and provides a lot of features, which are rarely or never used. In practice the source code compatibility works only for Java, while for C++ some more or less complex changes are always required.
- CORBA compliant brokers can freely interoperate with each other.
  All CORBA implementations use the same data exchange protocol, which has some overhead in terms of both data size and processing time, mostly due to data alignment requirements of the CORBA network exchange protocol.
- Supports widely used programming languages, like C, C++ and Java.
  While the language mapping standards have been issued for some of the new popular PLs, most of them have never been implemented due to their complexity.

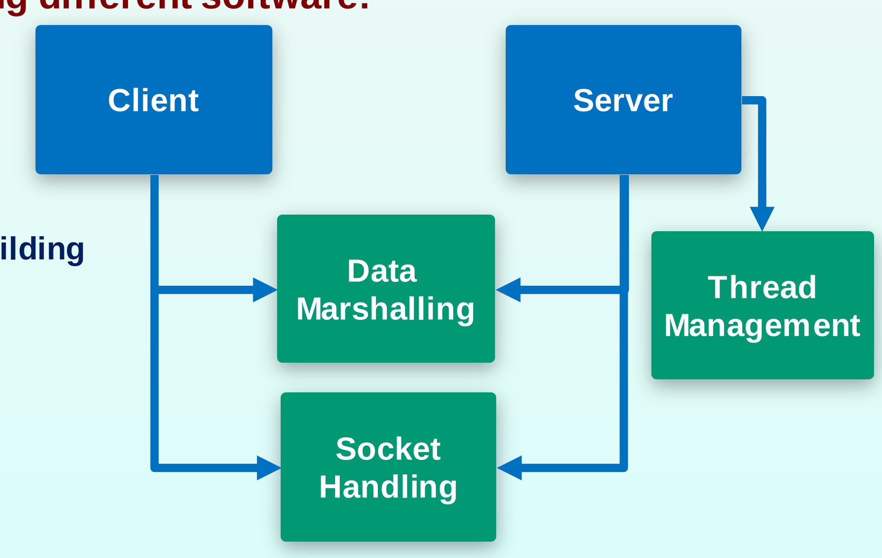


3. The modern trends in the IPC software market

Fast evolution of computing systems and network technologies brought into life a huge number of software communication systems. They are varying in many key aspects, including communication model, implementation level, supported programming languages, communication protocols and so on. Some of those systems are applicable only for specific domains while others are general purpose systems, which can be used for implementing any possible type of communication.

There are three main aspects involved in distributed system development and the modern tendency is to handle them independently using different software:

- **Marshalling libraries:**
  - **Json, MessagePack, Google Protobuf, etc.**
- **Communication libraries:**
  - **Boost ASIO, ZeroMQ, NanoMsg, etc.**
- **Thread Management:**
  - **Boost Thread, C++11 STD library, Intel Thread Building Blocks library, etc.**



The absence of a language neutral interface description Is compensated by modern improvements in programming languages like for example C++11.

```
class MyServer : public tdaq::rpc::Server {
  public:
  MyServer() : tdaq::rpc::Server(zmq::socket_type::rep) {
    add_method("echo", &MyServer::echo, this, std::placeholders::_1);
    add_method("add", &MyServer::add, this, std::placeholders::_1, std::placeholders::_2);
  }

  std::string echo(const std::string& msg) {
    return "This is MyServer::echo, returning: " + msg;
  }

  int add(int x1, int x2) {
    return x1 + x2;
  }
};
```

Taking into account the ATLAS TDAQ Online Software requirements, using a combination of low-level libraries for IPC implementation is a very attractive option.

4. Using ZeroMQ for Network Transport

ØMQ is a low-level C-style library for reading/writing something which looks like plain old sockets. All state management and error handling complexities are hidden.

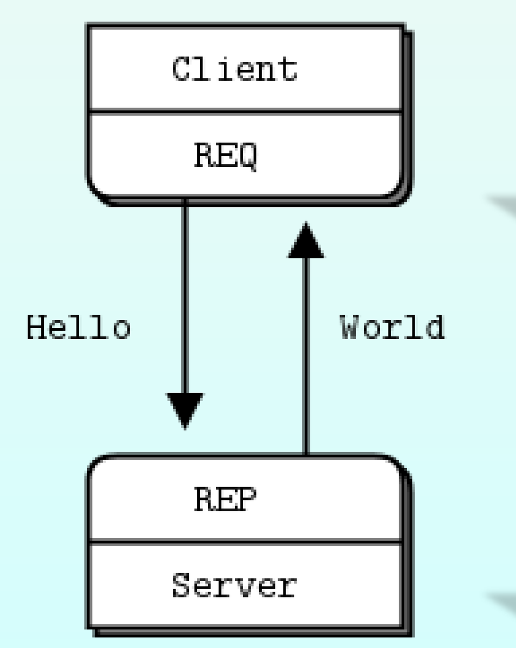
ØMQ supports most of the widely used Programming Languages

Bash, C, C++, C#, Common Lisp, D, Erlang, Go, Haskell, Java, Lua, node.js, Perl, PHP, Python, Racket, Ruby, Tcl, …

Development & Support model

- Large and active developer community
- Open Source software model

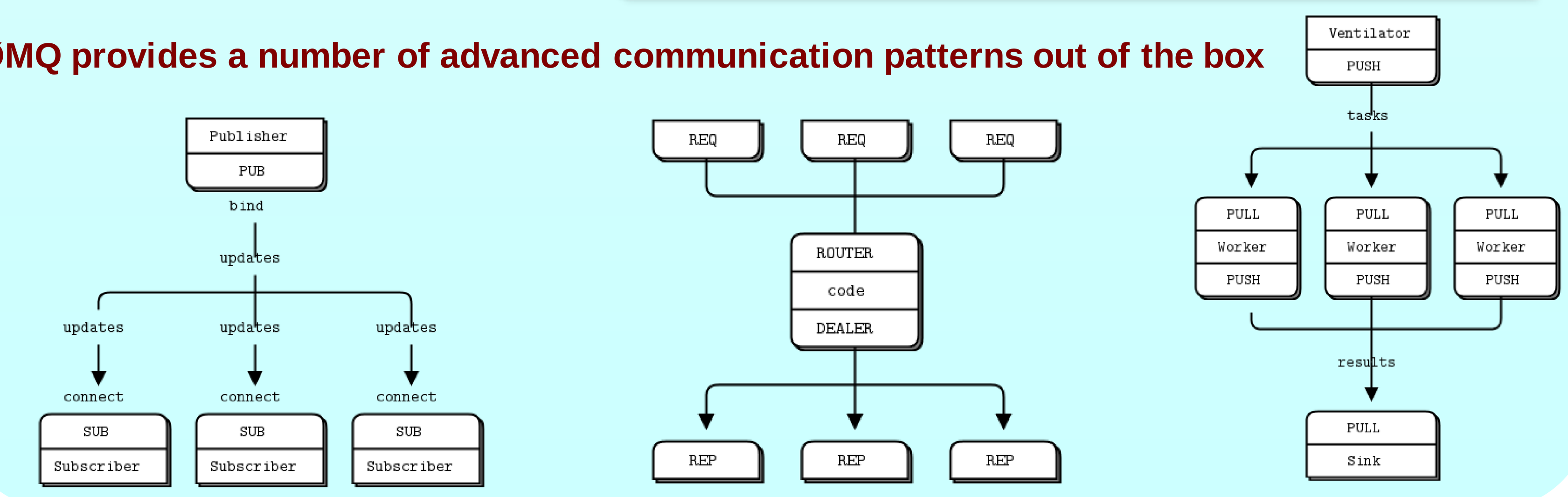
The simplest **REQ**uest-**REP**ly pattern




```
main () {                                                     Client
  zmq::context_t context();
  zmq::socket_t socket(context, ZMQ_REQ);
  socket.connect(tcp://localhost:5555");
  while(1) {
    zmq::message_t request;
    socket.send (request);
    zmq::message_t reply;
    socket.recv (&reply);
  }
}
```

```
main () {                                                     Server
  zmq::context_t context();
  zmq::socket_t socket(context, ZMQ_REP);
  socket.bind (tcp://*:5555");
  while(1) {
    zmq::message_t request;
    socket.recv (request);
    zmq::message_t reply;
    socket.send (reply);
  }
}
```

ØMQ provides a number of advanced communication patterns out of the box

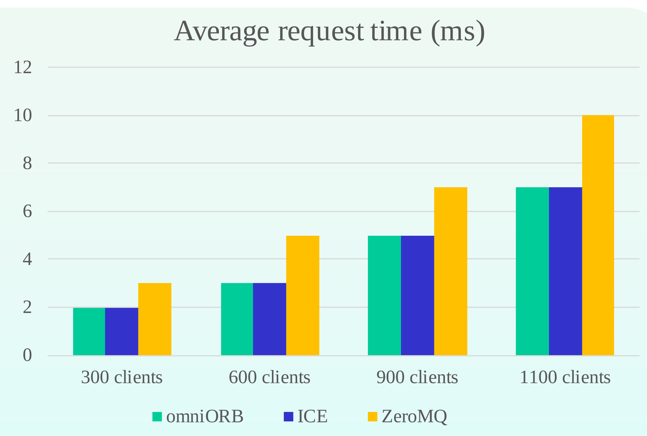


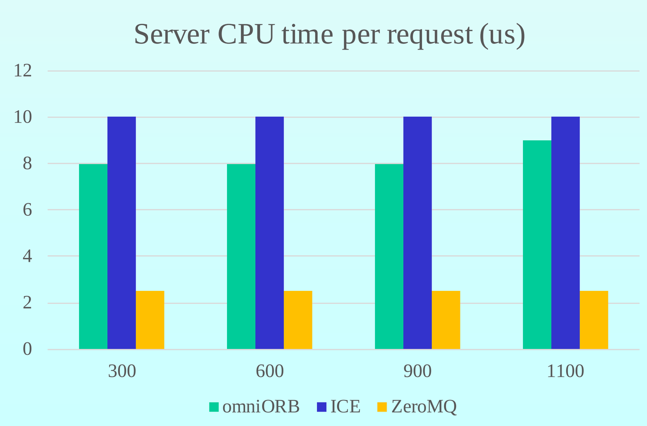
5. ØMQ Performance and Scalability

To understand the performance and scalability of ØMQ several tests have been performed.
For comparison we have been using the omniORB CORBA broker and the ICE framework provided by the ZeroC company. The latter one is a modern CORBA-like object-oriented RPC framework, which is free of many CORBA drawbacks, so it's an interesting candidate for performance comparison.

The hardware configuration used in testing:
Servers were running on the same computer: Intel Xeon E5645 4 cores 2.4 GHz, 24 GB RAM, 10Gb Ethernet
Clients were equally distributed over 100 computers: Intel Xeon E5420 2.5 GHz, 16 GB RAM, 10Gb Ethernet
All servers used the following configuration: 1 I/O thread, 20 worker threads
Clients send 1-byte string to the server and receive the same string back as fast as they can

Test results
The plots on the right present the test results. The first one shows average time for one request for all three systems and different number of concurrent clients. The second plot shows the number of CPU cycles the server spent to process a single request. The plots show that all systems have excellent scalability and offer very good performance. ØMQ spends a bit more real time for a single request, probably because the way in which requests are handled on the client side is different compared with the other two systems.
ØMQ does not write data to the socket from the user thread, but just places the data into a queue which is handled by another dedicated thread. This thread reads the data from this queue and sends it to the socket.
At the same time ØMQ shows significantly smaller CPU usage at the server side due to a very small overhead compared with the complex frameworks implemented by ICE and omniORB.





6. Conclusion

The CORBA standard has a long and successful history, but now the interest of the development community has shifted away from universal frameworks to a flexible combination of small independent libraries.

Using this approach for distributed systems implementation gives a number of advantages compared with the utilization of a traditional high-level object-oriented framework:

- **Performance – the network transport library provides a very low and efficient interface**
- **Simplicity – the API is very simple yet powerful. With few lines of code one can implement a complex distributed system.**
- **Flexibility – one can use only functionality which is required by the specific application thus avoiding unnecessary overhead.**

We are now considering ØMQ as the main candidate for the replacement of CORBA within the ATLAS TDAQ Online Software.