

Testing DLT Platforms and Infrastructures

This overview showcases Exactpro's DLT-specific testing capabilities: our approach to functional and non-functional testing of distributed systems and case studies illustrating our experience with testing production-grade DLT platforms across multiple financial industry use cases.

BUILD SOFTWARE TO TEST SOFTWARE

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SOFTWARE TESTING FOR DLT PLATFORMS

Software testing for financial technology platforms built with DLT has multiple aspects and is, therefore, associated with a whole set of requirements to the test harness required to support it.

Test tool requirements:

- Open interface and technology stack diversity: to provide intelligent interaction with many widely adopted network protocols as well as API, UI, DLT and cloud endpoints;
- Configuration agility: to build complex test instruments capable of executing sophisticated test algorithms, including model-based testing approaches, to address complex fintech use cases;
- Data governance: to enable better access to test evidence and smart analytics for governance and regulatory compliance;
- End-to-end testing capabilities: to support extensive test libraries covering complex business life cycles and perform system verification at the confluence of functional and non-functional requirements;
- High-volume automated testing: designed to perform autonomous test execution of more functional tests under load to improve test coverage, system quality and resilience.



FUNCTIONAL TESTING FOR DLT PLATFORMS

Functional testing of DLT platforms suggests a number of test activities complementing functional checks typically performed to assess the correctness of a test system's behaviour.

DLT-specific test harness capabilities:

- Nodes deployment with an ability to change the configuration
- CorDapps deployment
- Nodes administration
- Nodes registration in the Network
- Trigger transactions generation, verification and distribution across the nodes
- Database verification and monitoring (low-level ledger update validation)

Additional capabilities:

• JVM statistics gathering





EXACTPRO'S APPROACH TO FUNCTIONAL TESTING OF DISTRIBUTED LEDGER TECHNOLOGY PLATFORMS





FUNCTIONAL TESTING FOR DLT PLATFORMS (continued)

Covering business flows on top of DLT networks

Interbank payments: Position update business flow

3 steps on the ledger side:

1st Initialisation of positions

2nd Trade creation and participant notification

3rd Positions update

At each of the steps, the test framework provides different methods to validate the endpoints, inputs and outputs.

The actual business flow steps and validation check items are transformed into the test script. Upon its execution, the test tool's Report UI provides a detailed report showing deviations from the expected behaviour.

Example based on Hyperledger Fabric





Facts on the ledger:



shared between bank B and CCP

shared between all



FUNCTIONAL TESTING FOR DLT PLATFORMS (continued)

IRS & CDS Swaps Lifecycle Module Based on ISDA CDM

Business flow:

The test harness simulates a participant who submits a trade. The script sets the ledger time to the next fixing date and simulates floating rate fixings by the market data provider. Then it "time travels" to the next reset date (payment date) and generates derived events.

Test capabilities:

- External system/participant simulator
- In-built schedule to prompt interactions with DLT network
- Testing model for test input and output generation
- Test script containing a template with a swap contract info (swap type and structure) and lifecycle specifics (e.g. segregation of trades or multiple contracts by one member, event schedules, etc.).



NON-FUNCTIONAL TESTING FOR DLT PLATFORMS

Non-functional testing of any platform is complex: it requires comprehensive configuration and, most often, preliminary development activities.

To run automated non-functional tests, one needs to monitor various metrics of the platform under test and its hardware usage. Having the option to start/stop/adjust load injection or other actions based on the current system state is also a must. The Exactpro framework for automation in testing allows to initiate flows across large-scale networks of nodes of a distributed system. To gather metrics and visualise the results, our test framework uses its monitoring capabilities built using open source third-party tools.

FAILOVER TESTING

To ensure there is no loss of service in transaction notarisation with a variety of test CorDapps, the tool forces node failures within the network and checks the system's behaviour.



LOAD & STRESS TESTING

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To determine the maximum throughput processing on the reference infrastructure with no chain history and one state per transaction, the PerfTest CorDapp and a specific custom flow were used for a specific use case. This minimised the number of variables and allowed us to report the values in a meaningful way. In a DLT network, transaction throughput (measured in TPS) is a function of many dimensions (attachments, chain length, number of input/output states).





PERFORMANCE TESTING

Latency measurement

For test execution, latency characteristics are determined at certain quanta of the maximum transaction processing rate with a no-chain history.

Upon test run, the test tool generates a report on latency values with pre-determined input rates (usually, 25, 50, 100, 150% of the maximum value). For each input rate, the report specifies:

- average latency per transaction processing (mean and 99th percentile)
- average compute time (mean and 99th percentile)
- latency and compute time distribution charts

Soak testing

Soak tests aim to evaluate the ability of a system under test to sustain load for prolonged periods of time.

In the example below, we set up a DLT environment on Microsoft Azure, with a multi-threaded RPC injector distributed across multiple global locations to initiate flows across large-scale networks of nodes against a remote network outside of the framework. Docker images are configured to run specific Corda enterprise versions, CorDapps and RPC clients for instantiation of test flows. System monitoring is implemented via open-source tools, such as DataDog, Graphite (for JMX stats), and bespoke scripts for additional memory monitoring.

For each node with a variety of test DApps, the test tool determines memory usage.

In our example, two DApps are used to drive transactions through the network over an extended period of time, with a pre-determined input rate approaching its maximum value. Memory usage of a node JVM is monitored over time while it is processing tens of millions of transactions (e.g. whether it grows, if memory is released, whether the node fails and/or restarts, etc.).





EXACTPRO WINS "BEST IN OPERATIONAL RESILIENCY" MARKETS CHOICE AWARD

Exactpro is honoured to be recognised as "Best in Operational Resiliency" in the 2021 Markets Choice Awards held by Markets Media Group.

Exactpro's next-generation test automation platform – th2 – offers financial infrastructures a comprehensive end-to-end technology agnostic Al-driven test automation solution which aims to help regulated capital markets participants stay compliant and resilient to disruption, while focusing on innovation and having the freedom to embrace emerging technologies, most relevant to their clients' needs. Built with these goals in mind, th2 brings unprecedented flexibility, breadth and depth of software testing to the financial industry in the drive for improved operational resilience.

The th2 toolkit is designed to enable automation in functional and non-functional testing for complex distributed transaction processing systems, such as securities trading systems and exchanges, banking, brokerage, post-trade (e.g. clearing, settlement, custody), and payments platforms. With the aim to increase the tool's accessibility across Exactpro's international client base, the th2 source code was released to GitHub in December 2020.

Natalia Kryukova, th2 platform Manager, Exactpro, said: "Considering that the subject of operational resiliency has been at the forefront of financial technology for the past year, the



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award is an immensely valuable recognition of Exactpro's continuous effort to address the increased industry demand. This award is an important achievement as our strategic focus remains on the assessment of the clients' financial technology for robustness and reliability."

ABOUT MARKETS MEDIA

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EXACTPRO AWARDED INNOVATION ACCOLADE FOR BLOCKCHAIN PROJECT WITH R3

QA AWARDS 2020 Excellence in software quality assurance * * * * * * * *

AWARD WINNER

Exactpro, a leading software testing provider for financial market infrastructures, is pleased to announce the receipt of QA Financial's "Automation Technology Project of the Year: Exactpro and R3" award, in recognition of its work with R3's Corda Enterprise Distributed Ledger Technology ('DLT').

Exactpro delivers testing services underpinned by tools and proven methodologies as a result of a significant R&D investment. The project saw the extension of comprehensive functional and non-functional capabilities to meet the new and exacting testing requirements of the latest Corda Enterprise DLT release, itself forming the basis of a few significant new FMI-driven platforms.

Matthew Crabbe, CEO of QA Financial, says: "QA Financial's annual awards recognise innovation and achievement in software quality assurance in financial services. Exactpro's work with R3's distributed ledger platform is a great example of how important software testing is to the development of new financial technologies, and how automated testing technologies in particular are critical to the functioning of complex markets." Commenting on the award, losif Itkin, co-CEO of Exactpro, says: "We are delighted to be recognised for our progress with testing in the DLT space in conjunction with R3, to help them deliver a cutting-edge, robust, and performant enterprise-grade platform for use by their growing number of production clients. Our achievements ensure that future DLT projects match or surpass the level of reliability of their legacy counterparts and bolster our status as a market leader in software testing for systemically important infrastructure service providers in the future."

"There are many challenges in testing distributed ledger platforms, including the interoperability of nodes in the network and the near infinite permutations of connections between them. It's a challenge that expands into hundreds of millions of tests, and automation is the only viable solution," added James Carlyle, CIO, Head of Production, R3.

Exactpro continues to innovate in new technologies such as artificial intelligence and blockchain, bringing state-of-the-art testing methods to FMIs implementing next generation projects.



EXACTPRO NAMED MANAGED SUPPORT SERVICES PROVIDER OF THE YEAR



AWARD WINNER

Risk.net is the world's leading source of in-depth news and analysis on risk management, derivatives and regulation. The annual Risk Technology Awards nominations are granted after a thorough review by a panel of judges consisting of industry experts and Risk.net editorial staff. A total of 142 entries in 23 categories were received this year.

Firms entered the awards and were judged 'primarily on their achievements in the pre-coronavirus age', as the announcement states. How they leveraged their tools and adapted approaches in what came next, though, is no less, if not more, important. However, in software testing for complex distributed systems, such as banking and capital markets systems, outages and abnormal peaks in transaction load, numbers of connections or asset prices are something one should prepare for head-on as part of business-as-usual activities. "Rather than trying to predict future circumstances, we should stress technology platforms to their limits, with rigorous checking for monitoring and alerting mechanisms, and system failover capabilities," says losif Itkin, co-CEO and co-founder of Exactpro. "Instead of waiting for a catastrophe to happen, we emulate it during our tests, thus providing stakeholders with the information on the real state of the platform and its readiness for the unexpected."

"Ensuring the highest quality and reliability of our clients' technology platforms has always been Exactpro's priority," adds losif. "It's an honour to have our approaches recognised at such a high level."



In this Risk.net interview, Alexey Zverev, Exactpro co-CEO and co-founder, talks about mitigating risks while driving innovation in the time of high volatility and explains what made Exactpro stand out among the contestants. You can proceed to watching the interview with Risk.net via the QR code on this page.



IS YOUR DAPP REGULATORY-GRADE?

By Alexey Zverev, CEO and co-founder, Exactpro

Distributed ledger technology (DLT) innovation is an important trend shaping the financial services industry. It's no surprise that under the pressure of ongoing overall digital transformation, many financial institutions are keen to adopt DLT in development of their platforms. However, when the innovation is introduced on a scale of a major capital market participant, its potential impact is likely to be shared by a larger financial services community. To facilitate the smooth transition towards the emerging technologies, the regulatory bodies require systemically important financial market infrastructures to ensure that while innovating, they also stay operationally resilient.



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Operational resilience: regulatory perspective

Following last year's disruptive events, the regulators continue to increase their focus on the financial sector's operational resilience, i.e. the ability to prevent, adapt and respond to, recover and learn from operational disruption [1].

In the UK, the 'Building operational resilience' Policy Statement, produced by the FCA, PRA and Bank of England in March 2021[2], introduces new rules to go into effect early next year. In the preceding discussion paper dated July 2018 [1], the regulatory bodies outline the main challenges to the operational resilience and provide guidance on identifying important business services and assessing the impact of potential disruptions.

The European regulatory framework is consistent with its UK counterpart in terms of these challenges and sees emerging technologies along with growing dependency on data as generating a need for stronger operational resilience [3].

As outlined in the EC's regulation on a pilot regime for FMIs based on DLT, the operators of market infrastructures are expected to "ensure that the overall IT and cyber arrangements related to the use of their DLT are proportionate to the nature, scale and complexity of their business" [4]. To fully comply with this requirement, regulated entities need to establish adequate software testing procedures for their core platforms. But what sort of testing would be considered regulatory-grade?

Achieving regulatory standard in software testing

Regulatory-grade testing is software testing that helps the firms ensure "continued transparency, availability, reliability and security of their services and activities, including the reliability of smart contracts used on the DLT" [4]. It also provides the information, sufficient for making robust decisions. In achieving this, it is crucial that testing activities generate regulatory-grade data, the data that satisfies the requirements of integrity, security and confidentiality, availability, and accessibility.

Speaking broadly, in order to meet regulatory requirements, you need to prove the ability to manage your application providing fair. consistent uninterrupted transaction and management service for all participants. The key for this ability is extensive knowledge of the system that you are going to manage. The only possible way of obtaining such knowledge is via experiments and observation, which is basically what software testing is. For those trying to develop and maintain complex financial systems, insufficient testing leads to inevitable failure.



Understanding the challenges

However, testing the systems based on distributed blockchains is not a trivial task. For comparison, in electronic trading, all transactions in modern stock exchanges are processed by matching, clearing and settlement engines hosted in fully controlled



data centers managed by corresponding organizations. In contrast to that, in distributed blockchains, transactions are processed by a distributed network of nodes hosted and managed by the participants. This introduces a number of complications for software testing, such as:

- impossibility to simulate adequate transactions without a production blockchain;
- non-deterministic response due to complexity of the state of the network caused by distributed processing;
- diversity of APIs, platforms, and application versions within the network;
- complexity of smart contract transactions involving multiple participants simultaneously;
- poor integration with legacy systems outside of the network;
- absence of a central processing point allowing you to deduce and drill down the chain of events that led to particular outcomes.

Addressing the complexity: Processes, Platforms, People

Key ingredients to accommodate software testing of a regulatory grade are Processes, Platforms and People.

Setting up software testing process

At Exactpro, we understand the software testing process as an empirical technical investigation conducted to provide stakeholders with the regulatory-grade information about the quality of the product or service under test.



The key characteristics of a good testing process are:

- Focus on observation: aiming to discover new information rather than confirming the assumptions;
- Testing is relentless learning: meaningful testing demands sufficient time investment;
- Early testing: testing activities should start as early as possible during the requirement definition stage and continue throughout the whole duration of the project;
- Independent perspective: testing team has an ability to form objective judgements and a voice to advocate for proper governance;
- Test automation: efficient testing is impossible without employing test tools not for the sake of automation per se but rather to augment testing capabilities of highly qualified software testing engineers.

Regulatory-grade testing requires a significant investment of time of highly skilled resources. It is important that this talent is providing an independent view: they are not the same people who built the platform in the first place, e.g. in-house developers or a software vendor.





1 - As the first step, we must ensure that basic scenarios of the core functionality pass the tests in a semi-isolated controlled environment. 2 - The next step is end-to-end testing in a production or production-like network, consisting of an environment, a test version of your application distributed across this environment, and Test Agents - pieces of software that will facilitate testing and collect important information.

Using this toolkit will enable you to:

- load the system with appropriate flow of transactions covering important scenarios;
- simulate outages in the network and test application;
- simulate complex conditions your application is required to sustain.

3 - Finally, from all these activities you will need to collect data containing sufficient information to understand the outcome of the tests. This data must be processed and analyzed to extract the knowledge about the system behavior and draw insights needed to provide uninterrupted service.

Building regulatory-grade platforms

The processes should be supported by the platforms. To provide the regulatory-grade testing capabilities, a test automation framework should rely on the latest technology stack and support testing at the confluence of functional and nonfunctional approaches.

The extreme complexity of the task implies a set of requirements for the testing framework that are crucial to ensuring an appropriate level of quality assessment. First of all, a technologically advanced testing tool fit for the task of testing distributed apps on a regulatory grade requires the ability to invoke tests through a variety of platforms and APIs along with the potential to run many different tests many times. Another important requirement is the possibility to simulate important conditions by deploying the test code into the network. To enable its users to draw insights from system behavior, the testing harness should be able to process high volumes of data. On top of that, the ability to invoke and analyze the outcome of chaotic scenarios as well as to deal with non-deterministic responses entails the requirement of a tool being enhanced with a strong analytics module.

To meet the complexity level of the present-day distributed non-deterministic platforms, we developed a software testing framework satisfying these requirements.

th2 [5] is an open source toolkit providing end-to end functional and non-functional test automation for complex distributed transaction processing systems. Built as a cloud native Kubernetes-driven solution, it aims to help regulated entities stay compliant and resilient to disruption, while focusing on innovation and having the freedom to embrace emerging technologies:

- it is a multi-platform framework with a powerful API, enabling intelligent interaction with many widely adopted network protocols as well as API, UI, DLT and cloud endpoints;
- its microservices architecture allows building complex test instruments and execute sophisticated test algorithms;



- it supports the GitOps paradigm, enabling CI/CD pipeline integration;
- it is designed to perform autonomous test execution;
- ready for implementation of Al-driven test libraries for machine learning and advanced data analytics.

Though this set of test automation capabilities may seem comprehensive all by itself, it is still not enough to establish a robust software testing approach of a regulatory scale without highly-skilled professionals to make processes and platforms work together.

Supporting processes and platforms with people

If asked to outline core qualities of the people who are apt for the task of testing of complex distributed systems, the following key characteristics can be suggested:

- a software tester's mindset to actively pursue exploring of the system they test;
- software developer's skills to be able to create code for tests that adequately cover complex behavior of the systems under test;
- deep understanding of business logic and technology behind the platform being tested.

Hard and soft competencies that are needed to operate technologically advanced platforms and implement the required processes are outlined under the umbrella of the Zero Outage Industry Standard (ZOIS) [6], an industry association developing best practices to ensure the highest quality of IT platforms.

Conclusion

The regulators expect the financial institutions operating complex distributed platforms to be able to maintain high availability and resilience to disruption, even in a chaotic environment. This can only be achieved by intelligent end-to-end testing of a distributed application in both business-as-usual and disruption scenarios under production-like conditions and in a full-scale network. That requires an investment of the time of highly technical resources and advanced test tools.



With DLT projects being implemented on a greater scale, the financial services industry is rapidly transforming adopting new technology and, then, regulatory standards. In such a context, it is very important to establish the practice of DLT innovation that is supported by extensive regulatory-grade quality assessment.

REFERENCES

[1] Building the UK financial sector's operational resilience: Discussion paper | DP1/18 by the BoE, PRA, and FCA. July 2018.

[2] Operational resilience: Impact tolerances for important business services: Policy Statement | PS6/21 by the BoE, PRA, and FCA. March 2021. [3] Proposal for a Regulation of the European Parliament and of the Council on digital operational resilience for the financial sector -COM(2020)595.

[4] Proposal for a regulation of the European Parliament and of the Council on a pilot regime for market infrastructures based on distributed ledger technology - COM(2020)594.

[5] th2 - an open source test automation framework: <u>https://github.com/th2-net</u>.

[6] Zero Outage Industry Standard Association: <u>https://zero-outage.com/</u>.



OUR LATEST DEMOS

th2 Implementation for Reconciliation Testing of the P8 Marketplace Built by Yaala Labs



The demo showcases a th2 implementation for reconciliation testing of the P8 marketplace platform built by Yaala Labs – a technology firm specialising in building mission-critical applications for global financial markets. P8 is a blockchain-enabled solution deployed on the cloud. For the full demo, please proceed to our website via the QR code.



ith2





Formal Verification of Solidity Smart Contracts: Implemented with th2 Automation Framework



The demo features a solution for the formal verification of smart contracts written in Solidity, implemented with the use of the th2 automation framework. We apply our approach to a smart contract which automates ERC-721 non-fungible token management for the NFT marketplace launched on the P8 platform developed by Yaala Labs.

For the full demo, please proceed to our website via the QR code.



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P8 NFT Marketplace Functional Testing with the th2 Automation Framework



The demo feature a th2 based implementation for the functional **testing of the NFT marketplace launched on the P8 platform** developed by Yaala Labs.

For the full demo, please proceed to our website via the QR code.







Functional Testing of CBDCs in the R3 Sandbox for Digital Currencies



The demo showcases a th2 implementation for the functional testing of issuance, management and distribution of CBDCs (Central Bank Digital Currencies) performed in the R3 Sandbox for Digital Currencies.

The Digital Currencies Sandbox is a SaaS offering powered by **Corda** – a DLT platform built specifically for highly regulated industries. The first release of the **R3 Sandbox for Digital Currencies provides** an environment for users to explore the possibilities of a distributed ledger technology solution for CBDCs in a wholesale setting.

For the full demo, please proceed to our website via the QR code.









Thank You!

About Exactpro

Exactpro is an independent software testing services provider for financial market infrastructures. Our clients are exchanges, post-trade platforms, and banks across 20 countries.

Founded in 2009, the Exactpro Group is headquartered in the UK and has operations in the US, Georgia, Sri Lanka, Lithuania, Armenia, Canada, the UK and Italy. The firm employs over 700 specialists.

Exactpro is involved in a variety of transformation programmes related to large-scale cloud and DLT implementations at systemically important organisations. Our area of expertise comprises API gateways, matching engines, market data, clearing and settlement, market surveillance, improving scalability, latency and operational resiliency.



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