FUNDAMENTAL
INTERACTIONS

MATCHING ENGINE TECHNOLOGY

Architecture,
Determinism, and
Comparison to Global
Exchange Platforms
2026

FUNDAMENTAL INTERACTIONS INC.

www.finteractions.com

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EXECUTIVE SUMMARY

In today's fragmented and highly regulated market landscape, trading venues face a critical choice: compromise on performance by using legacy systems, risk their intellectual property by outsourcing to competitors, or build on a foundation designed for modern independence.

Fundamental Interactions (FI) provides a high-performance, deterministic matching engine that resolves these trade-offs. Built on the same architectural principles as global leaders like CBOE, NASDAQ and MEMX, the FI platform delivers the deterministic sequencing, predictable low-latency, and audit replayability required by national-scale exchanges.

This white paper outlines the technical architecture, deterministic guarantees, and strategic benefits of the Fundamental Interactions platform.

EXECUTIVE SUMMARY

FI distinguishes itself through three strategic advantages:

Strategic Independence: Unlike "Exchange-in-a-Box" solutions that trap ATSs in a front-office-only model, FI is a pure technology partner. We ensure venues retain complete ownership of their data, matching logic, and intellectual property, eliminating the risk of leakage to exchange-operated competitors.

Technological Agility: Built on a modern, low-latency managed runtime with advanced concurrent memory management, Fundamental Interactions eliminates the historical trade-off between deterministic performance and development velocity. This architecture enables operators to design, test, and deploy bespoke order types and auction models significantly faster than platforms constrained by rigid, legacy C++ stacks—without compromising stability, determinism, or regulatory rigor.

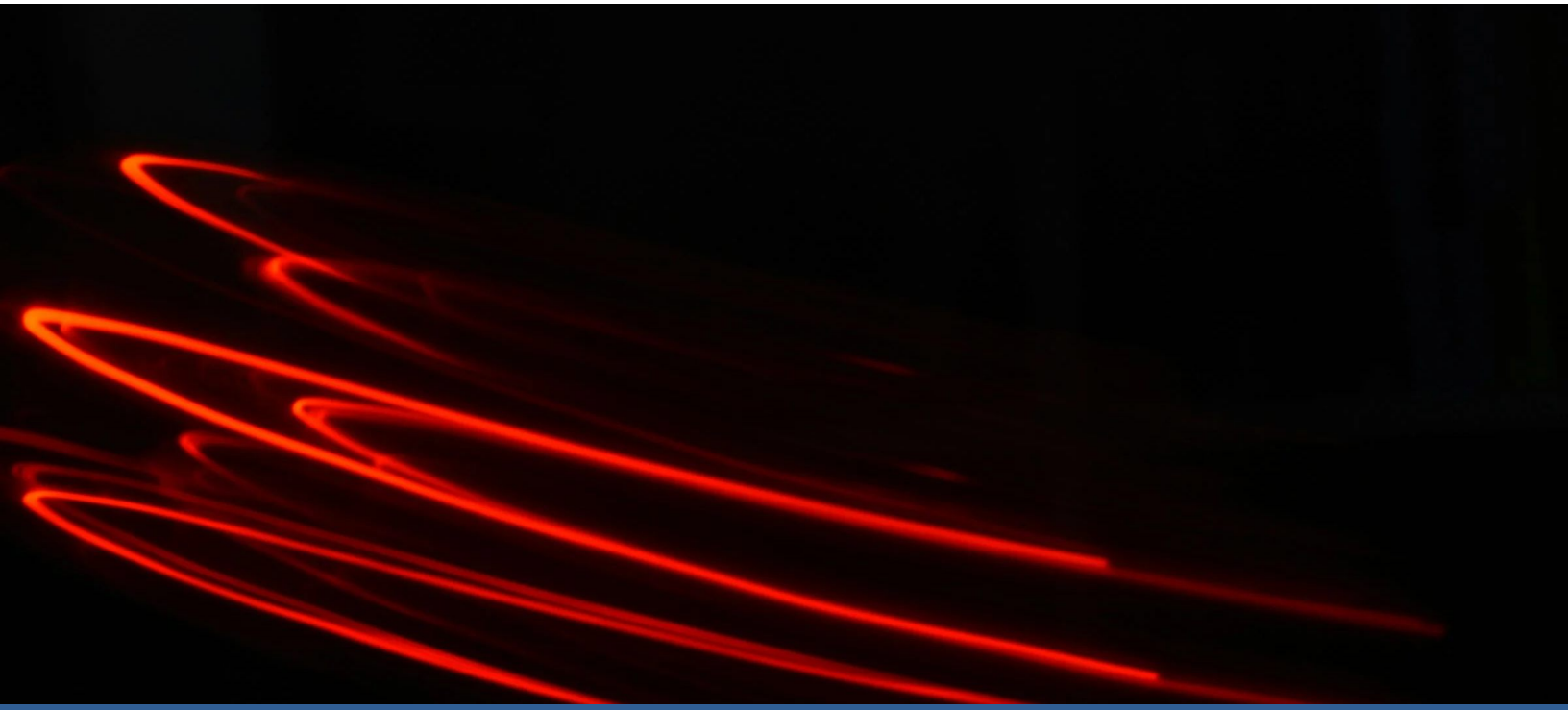
Unified Multi-Asset Execution: A single FI deployment can support traditional equities, private securities, and tokenized digital assets simultaneously. This unified framework reduces operational overhead and future-proofs the venue for the convergence of traditional and digital finance.

INTRODUCTION

Fundamental Interactions (FI) provides a high-performance, deterministic, single-threaded matching engine with configurable multi-threaded pipelines built for regulated markets, ATS operators, broker-dealers, alternative products, private securities, and digital-asset marketplaces.

The platform emphasizes reliability, replayability, predictable latency, and architectural simplicity—principles shared with the most respected modern exchange systems such as CBOE Titanium, MEMX, IEX, and NASDAQ INET.

This document summarizes FI's matching engine design, explains how determinism is achieved, and compares the architecture with leading global exchange technologies.



CORE ARCHITECTURE OVERVIEW

FI's matching engine is built on a clean, streamlined architecture centered around a **single, deterministic event-processing loop.**

Figure 1:

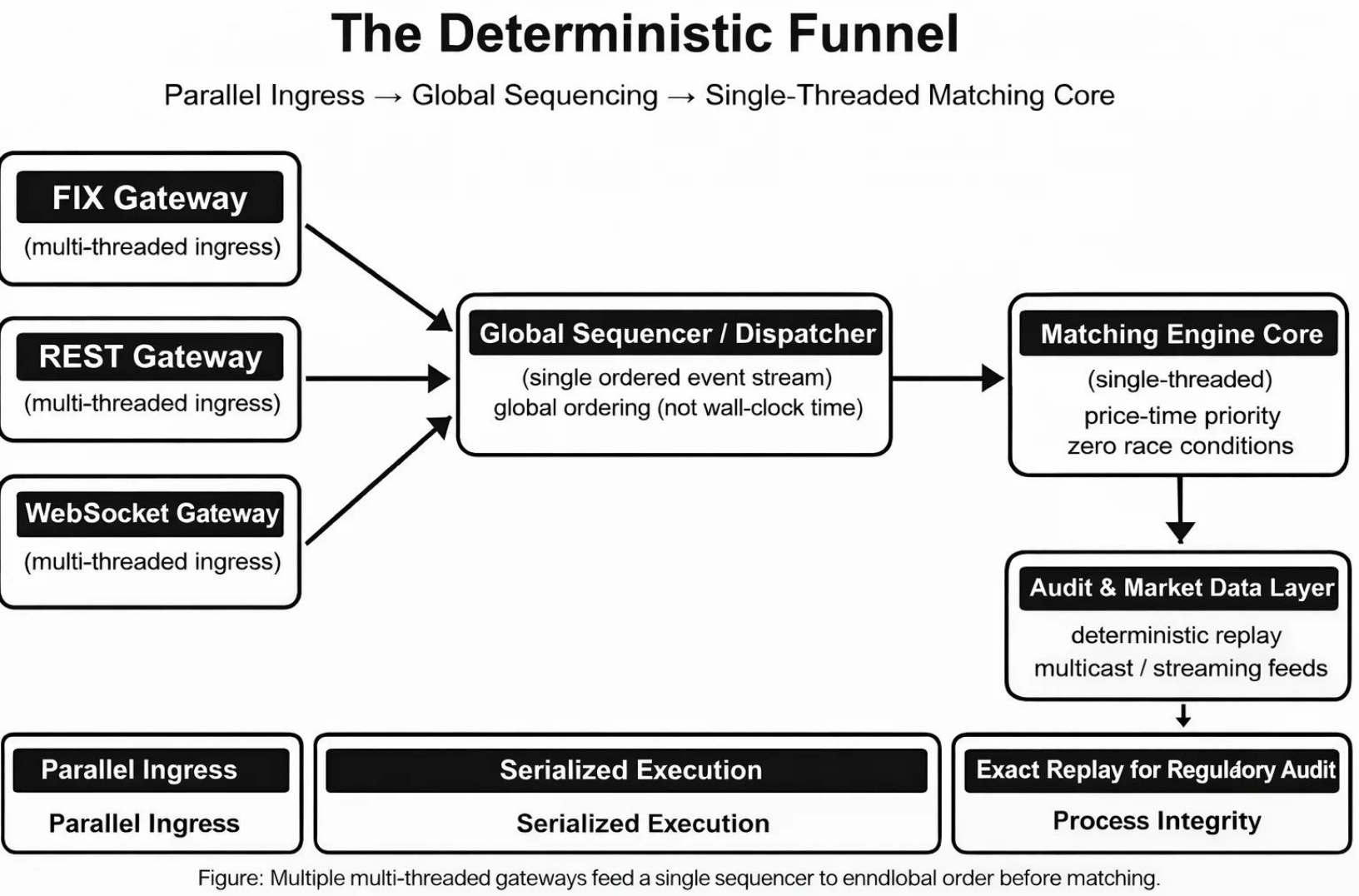


Figure: Multiple multi-threaded gateways feed a single sequencer to enndlobal order before matching.

CORE ARCHITECTURE OVERVIEW

All inbound order-related activity flows through a strictly ordered pathway:

Connectivity Layer: FIX, REST, WebSocket, and specialized APIs receive client orders, cancels, replaces, and administrative instructions.

Gateway Layer: Each inbound session normalizes and sequences messages. Gateway components apply session-level sequencing, timestamping, validation, and normalization. Multiple gateways feed into a unified event dispatcher.

Event Dispatcher: All validated messages are serialized into a single ordered event stream, ensuring that the matching engine receives events in a consistent, global order across all client sessions.

Matching Engine Core: The core engine processes each event sequentially. It maintains deterministic price-time priority order books, executes matching logic, generates trades, and produces market-data updates without concurrency or contention.

Audit and Market Data Layer: Execution results are logged in deterministic sequence for regulatory replay; market data is disseminated via multicast or streaming feeds. This architecture eliminates nondeterministic race conditions, reduces operational complexity, and ensures stable, predictable response times.

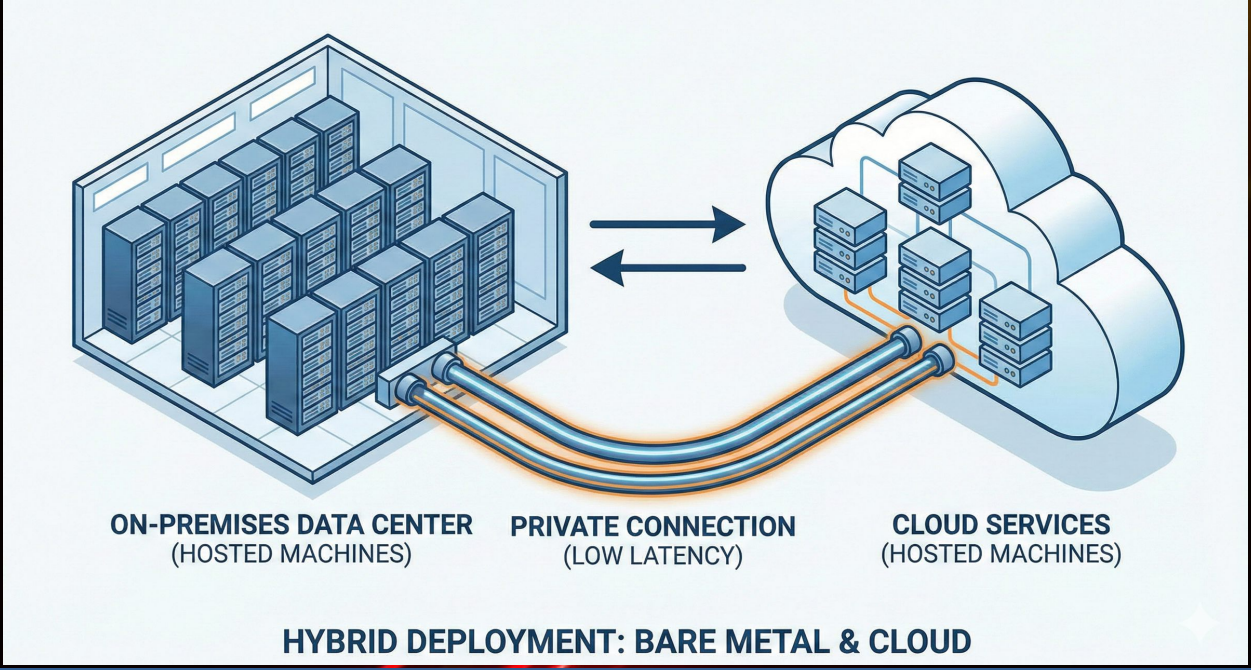
DEPLOYMENT FLEXIBILITY: BARE METAL TO HYBRID CLOUD

While the matching engine core is optimized for high-performance bare-metal environments typical of colocation facilities (e.g., NY4, LD4), the architecture is agnostic to the underlying infrastructure.

Bare Metal: For venues requiring the absolute lowest latency profile, the system deploys directly onto high-frequency servers with kernel bypass and solarflare optimizations.

Hybrid & Cloud Native: The platform's modern architecture supports containerized deployment within hybrid cloud environments (such as AWS Outposts or Google Distributed Cloud). This allows operators to leverage cloud scalability for data analytics and reporting while keeping the matching execution logic on dedicated local hardware to minimize jitter.

Figure 2:



DETERMINISM: WHAT IT IS AND HOW FI ACHIEVES IT

Definition of Determinism:

A deterministic matching engine guarantees that: Given the same ordered sequence of events, the system will always produce the exact same outcomes.

This includes identical matches and fills, queue positions, timestamps, book states, trade logs, and market-data outputs. Such behavior is essential for regulatory audits, ATS compliance, HFT model accuracy, and reproducible system behavior..

Deterministic Elements in FI:

FI ensures determinism through several architectural choices:

- **Single-Threaded Matching Core:** The engine processes events in one logical thread, eliminating parallel writes, lock contention, and race conditions.
- **Strict Global Event Ordering:** All gateway components produce a unified sequence of events before reaching the engine. Sequencing, not wall-clock timing, determines order.

DETERMINISM: WHAT IT IS AND HOW FI ACHIEVES IT

- **FIFO Price-Time Book Structures:** Queue order is strictly determined by the event sequence, producing consistent priority and fill behavior.
- **Stable Data Structures:** The engine avoids dynamic or randomized decision paths; every action follows a consistent, deterministic algorithmic flow.
- **Replay and Recovery:** Event logs can be replayed through the engine to reconstruct the identical state, a requirement for regulatory reproduction and incident investigation.

Deterministic Elements in FI:

The architecture maintains determinism even under high message rates. The core matching engine operates in a single-threaded deterministic loop to ensure consistent sequencing, while surrounding pipeline components—such as connectivity, risk checks, and market-data distribution—can be configured to run in multi-threaded modes to increase overall throughput.

Memory structures are pre-allocated and optimized to avoid unpredictable latency spikes, and when failover is required, the system uses log-based state restoration to preserve deterministic continuity.

LOW-LATENCY EXECUTION

Managed Runtime, Deterministic Latency:

The Fundamental Interactions platform operates within a managed Java runtime while delivering deterministic, low-latency performance required for regulated trading systems.

Earlier generations of Java trading systems experienced unpredictable latency due to Stop-the-World garbage collection pauses, creating the perception that Java was unsuitable for exchange-grade infrastructure. This limitation has been addressed with the introduction of the Generational Z Garbage Collector (ZGC) in Java 21+.

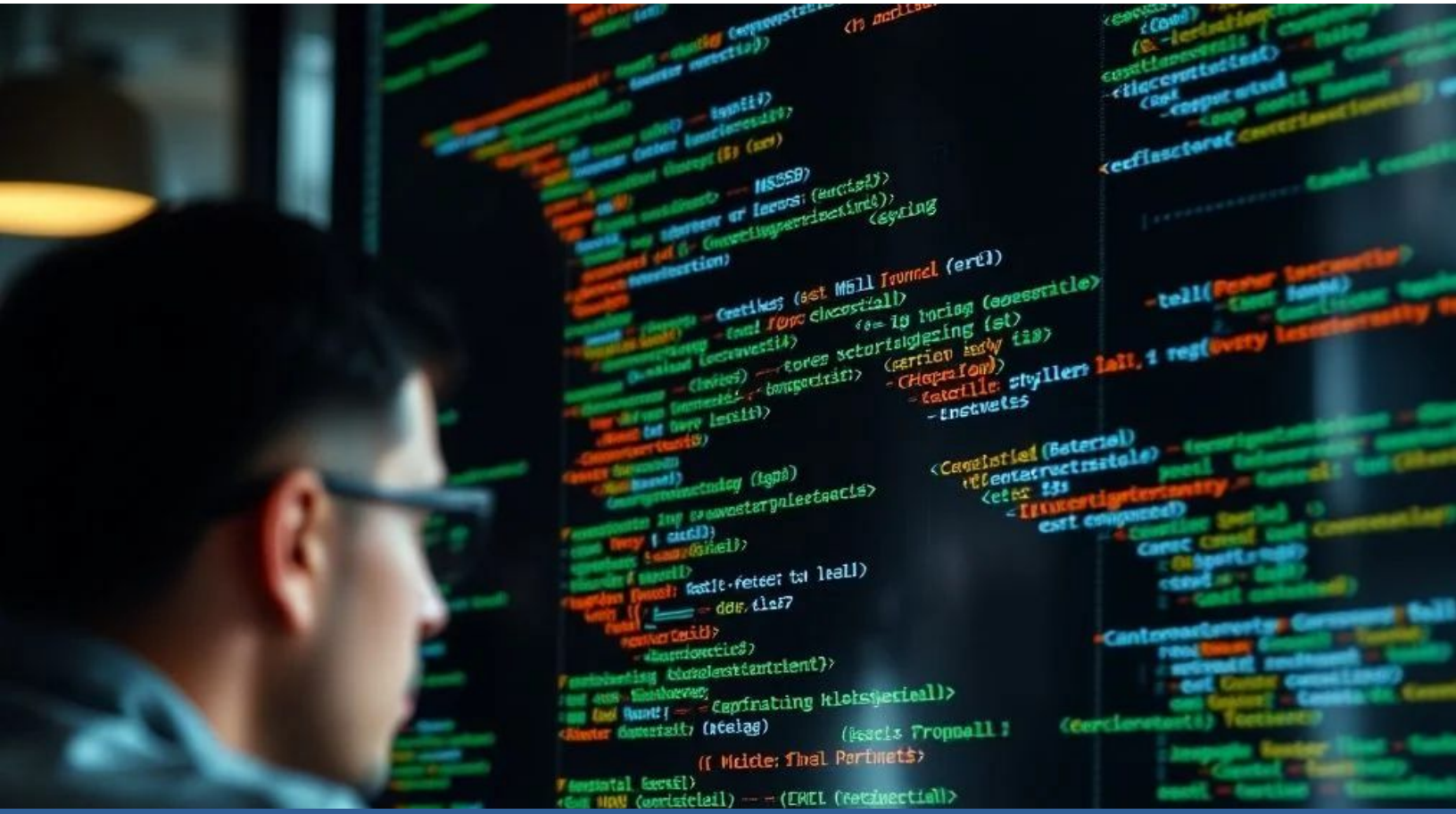
Fundamental Interactions leverages Generational ZGC's fully concurrent memory management to maintain micro-second pause times under all market conditions, effectively eliminating the historical latency risks associated with garbage collection.

- **Consistent Low Latency:** Garbage collection occurs concurrently with application execution, ensuring predictable latency independent of heap size or market load.

LOW-LATENCY EXECUTION

The Time-to-Market Advantage:

Unlike C++ environments that rely on manual memory management and complex pointer handling, the JVM enables rapid development and iteration. This allows Fundamental Interactions to design, test, and deploy bespoke order types and auction models significantly faster than platforms built on legacy technology stacks—providing a critical time-to-market advantage for ATSs seeking differentiation in an increasingly competitive landscape.



DATABASE ARCHITECTURE AND SCALABILITY

Industry Best Practices for Exchange Database Design:

Modern exchange and ATS platforms are designed to ensure that core execution logic remains isolated from persistence and analytics systems. Best practice architectures keep databases off the critical execution path, allowing order matching and price formation to occur in memory while databases handle durability, auditability, and post-trade processing.

Database Architecture in the FI Exchange Platform:

The Fundamental Interactions (FI) platform implements these industry principles through a database architecture that is fully decoupled from the deterministic matching engine.

- All order matching, book updates, and trade execution occur entirely in memory within the single-threaded core.
- No synchronous database writes occur in the execution loop.
- All persistence is driven asynchronously from the globally ordered event stream produced by the engine.

UNIFIED TRADING INFRASTRUCTURE

The Problem of Fragmentation:
Modern market operators increasingly support multiple asset classes—traditional securities, private securities, crypto assets, and tokenized real-world assets—each with distinct trading hours, settlement models, and regulatory requirements. Many firms address this by deploying separate systems per asset class, increasing cost, risk, and operational complexity. FI's unified execution framework also supports other asset classes such as options, futures, and FX to coexist within a single deterministic system.

Sub Set of Asset Classes Supported:

- **Traditional Securities:** Listed and OTC instruments trading during core and extended sessions, 24/5 trading integrated with established clearing, settlement, and regulatory reporting workflows.
- **Private Securities:** Controlled-liquidity instruments operating under exemptions, integrated with transfer agents and broker-dealer oversight.
- **Crypto Assets:** Continuous 24/7 trading with asset-specific precision and real-time settlement, while preserving deterministic execution guarantees.
- **Digital and Tokenized Assets:** Hybrid instruments combining blockchain-native settlement with traditional regulatory controls, supporting fractionalization and extended trading.

TECHNOLOGY COMPARISON WITH MAJOR EXCHANGE ARCHITECTURES

CBOE Titanium Platform—originally built from the BATS technology stack—is widely regarded as the industry benchmark for deterministic, ultra-low-latency design. FI adopts a similar design philosophy: straightforward, deterministic, and engineered for consistency rather than unnecessary complexity.

- Similarity Level: Very High. FI is architecturally closest to CBOE among major global platforms.

MEMX Platform—employs a modern C++ deterministic matching engine based on the same principles: single-threaded matching, strict sequencing, and simple, predictable execution logic.

- Similarity Level: High. MEMX emphasizes modern implementation detail; FI emphasizes reliability and deployability across multiple regulated and semi-regulated environments.

IEX Plaform—is deterministic but includes a 350µs “speed bump” and additional venue-specific logic. FI does not incorporate any artificial latency or discretionary routing behavior.

- Similarity Level: Partial. Both are deterministic engines, but IEX includes unique policy-driven logic absent in FI.

NASDAQ INET—remains one of the most sophisticated platforms in the world, with unmatched throughput. However, INET uses a more complex multi-threaded internal pipeline.

TECHNOLOGY COMPARISON WITH MAJOR EXCHANGE ARCHITECTURES

NASDAQ INET

Feature	Fundamental Interactions (FI)	NASDAQ INET
Matching Core	Single-threaded deterministic core with configurable multi-threaded pipelines for connectivity.	Multi-threaded internal pipelines with complex concurrency management.
Determinism	Yes — Enforced at the core through strict global sequencing.	Yes — Achieved through extensive sequencing and ordering logic.
Complexity	Low/Medium — Simpler, transparent design with optional multi-threaded components.	Very High — Intricate multi-thread pipeline architecture.
Replay / Audit	Very Strong — Log-based replay reconstructs identical engine state with minimal complexity.	Strong — But more complex due to multi-threaded internal event paths.

Similarity Level: Moderate. FI is simpler, while INET achieves determinism through complex concurrency management.

STRATEGIC INDEPENDENCE: THE RISKS OF EXCHANGE-OPERATED OUTSOURCING

As the barrier to entry for new Alternative Trading Systems (ATS) lowers, a new trend has emerged: major national exchanges offering **"Exchange-in-a-Box"** solutions. In this model, the exchange provides the technology stack, hosting, compliance, and operations, essentially turning the ATS into a pure "front office" entity responsible only for sales and management.

While this offers a seemingly turnkey path to market, it introduces critical strategic risks—specifically regarding Intellectual Property (IP) isolation and competitive misalignment.

When an Alternative Trading System outsources its core infrastructure to a major exchange, it **effectively hands over the "keys" to its business logic.** If an ATS is launching a niche model—such as a unique auction frequency, a specialized dark pool algorithm, or a specific sector focus—that differentiation is its primary value proposition.

- **The Conflict:** By running on an exchange's infrastructure, the ATS exposes its proprietary order types, matching logic, and client behavior data to a provider that is also a competitor.
- **The Risk:** There is little preventing the exchange provider from analyzing the success of the ATS's unique model and integrating similar functionality into their own national venue.

STRATEGIC INDEPENDENCE: THE RISKS OF EXCHANGE-OPERATED OUTSOURCING

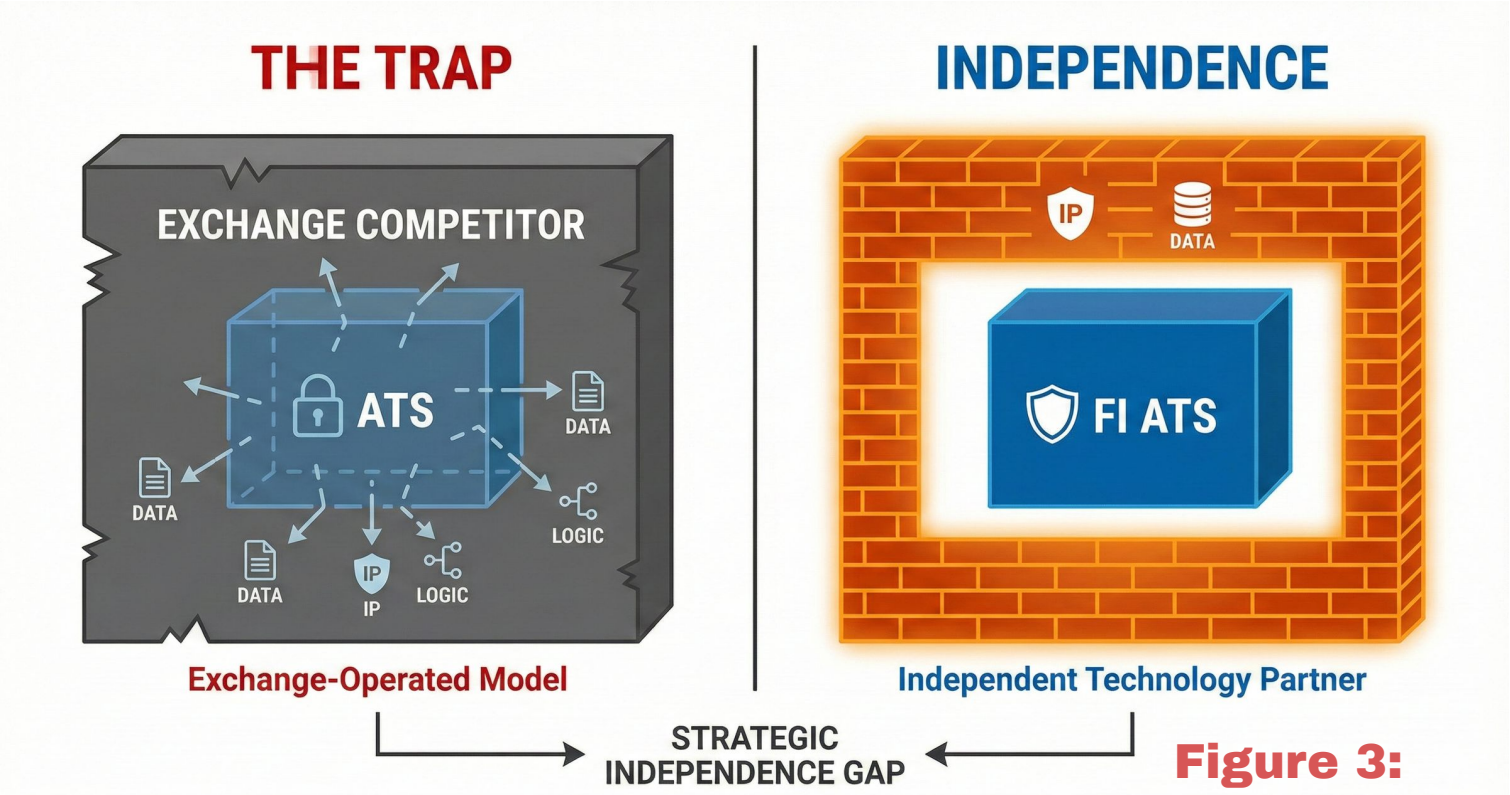


Figure 3:

Misaligned Incentives: Partner vs. Predator

Exchange-operated technology providers are incentivized to protect their primary business: the national exchange. They are unlikely to prioritize feature requests that cannibalize their own volume or disrupt their primary market structure.

- **Exchange Provider:** Operates with a "Coopetition" model. They serve the ATS today but may compete for the same order flow tomorrow.
- **Independent Partner (Fundamental Interactions):** FI operates as a pure technology vendor. We do not operate a venue, we do not compete for order flow, and we do not monetize client data.

STRATEGIC INDEPENDENCE: THE RISKS OF EXCHANGE-OPERATED OUTSOURCING

Comparative Analysis: Independent vs. Exchange-Operated:

Feature	Independent Technology Partner (FI)	Exchange-Operated Provider
Business Model	Pure technology vendor. Success is aligned with client growth.	Venue operator selling excess capacity. Potential conflict of interest.
IP Protection	**High.** The ATS owns its logic/data. The vendor has no incentive to copy it.	**Low**. The provider sees all logic and data and can replicate successful models.
Customization	**Agile.** Built for bespoke models, digital assets, and niche workflows.	**Rigid.** ATS must often adapt to the exchange's standardized "menu" of technology.
Exit Value	The ATS owns its tech stack (IP), increasing enterprise value.	The ATS is merely a service contract holder; the "tech" belongs to the provider.

BUILD VS. BUY: CHOOSING THE RIGHT PATH FOR AN ATS

The **build vs. buy decision** directly impacts an ATS's time-to-market, risk profile, cost structure, and strategic independence. Buying (including licensing or white-labeling a market center) typically accelerates launch by providing a proven core system that can be configured and integrated. This approach is well-suited for ATSs seeking to:

- Go live quickly and begin onboarding participants and liquidity
- Reduce early production risk (stability, regulatory reporting, audit and replay readiness)
- Focus engineering efforts on differentiation rather than foundational infrastructure
- Preserve strategic independence by partnering with a non-competitive technology provider

Building internally may be justified when competitive advantage depends on proprietary market microstructure or highly specialized matching logic.

In most cases, the optimal strategy is to buy the foundation and build the differentiation.

ADVANTAGES OF FI'S DETERMINISTIC ARCHITECTURE

- **Regulatory Confidence & Audit Readiness:** Exact state reproduction through log replay satisfies strict SEC and FINRA requirements. Regulators can verify exactly what happened at any microsecond, simplifying the audit process.
- **Predictable Behavior:** Algorithmic traders can model queue position and fill probability more accurately.
- **Operational Simplicity:** No multi-thread synchronization, shared locks, or parallel writer complexities.
- **Low Latency Variance:** Determinism naturally produces stable performance with minimal jitter.
- **Robust Failover:** State reconstruction is exact, enabling smooth failover and recovery.
- **Uniform Behavior Across Deployments:** Whether deployed for equities, digital assets, private securities, or bespoke marketplaces, the core logic behaves identically.

CONCLUSION

As demonstrated throughout this white paper, Fundamental Interactions delivers a deterministic, exchange-grade matching engine engineered to meet the performance, auditability, and control requirements of modern regulated markets

The platform is grounded in the same proven architectural principles employed by leading global exchanges—strict global event sequencing, predictable low-latency execution, and exact audit replayability—while maintaining a simpler and more transparent design.

At its core, FI prioritizes determinism as a first-order architectural requirement. A single, strictly ordered event stream, a single-threaded matching core, and log-based replay ensure that identical inputs always produce identical outcomes. This deterministic foundation simplifies regulatory review, enables precise audit reconstruction, and provides market participants with predictable, modelable execution behavior under all market conditions.

CONCLUSION

The platform is also designed for operational scale and durability. By decoupling persistence from the execution path and supporting flexible deployment models—from bare-metal colocation to hybrid environments—FI enables venues to grow from early-stage ATSs to national-scale or multi-asset market centers without re-architecting their core systems or compromising deterministic guarantees.

Equally important, Fundamental Interactions operates as a pure technology provider. Unlike exchange-operated “Exchange-in-a-Box” offerings, FI does not compete for order flow, monetize client data, or retain visibility into proprietary market logic. This ensures that venues maintain full ownership of their intellectual property, market design, and client relationships—preserving strategic independence and long-term enterprise value.

CONCLUSION

Figure 5:

CONCLUSION

Finally, FI's unified execution framework allows traditional equities, private securities, digital or tokenized assets, as well as other asset classes such as options, futures, and FX, to coexist within a single deterministic system. This unified approach reduces fragmentation, enforces consistent controls across asset classes, and positions operators for the continued convergence of traditional and digital markets.

In an environment where market operators must balance regulatory certainty, operational resilience, and strategic control, Fundamental Interactions provides a modern, deterministic foundation built to scale with both market complexity and evolving regulatory expectations.

CONCLUSION

Figure 6:

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