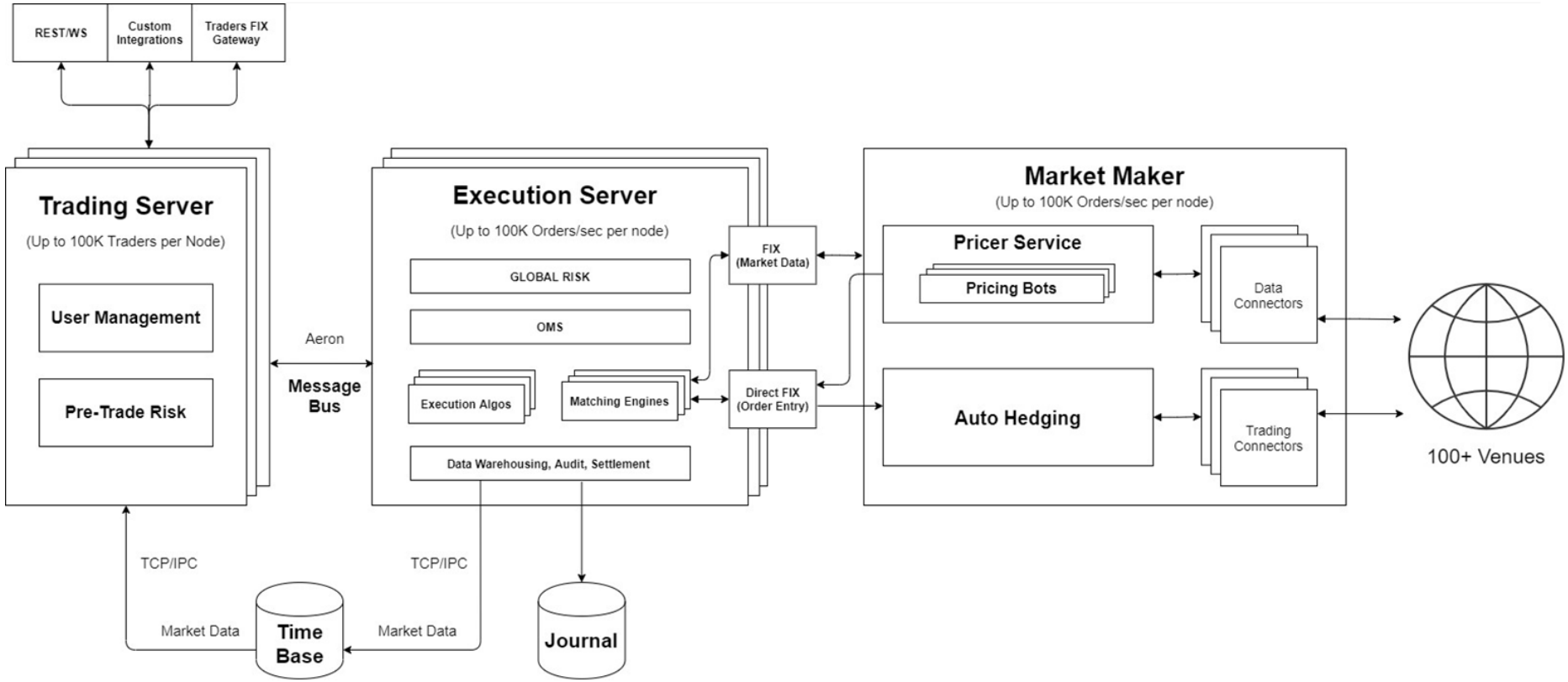
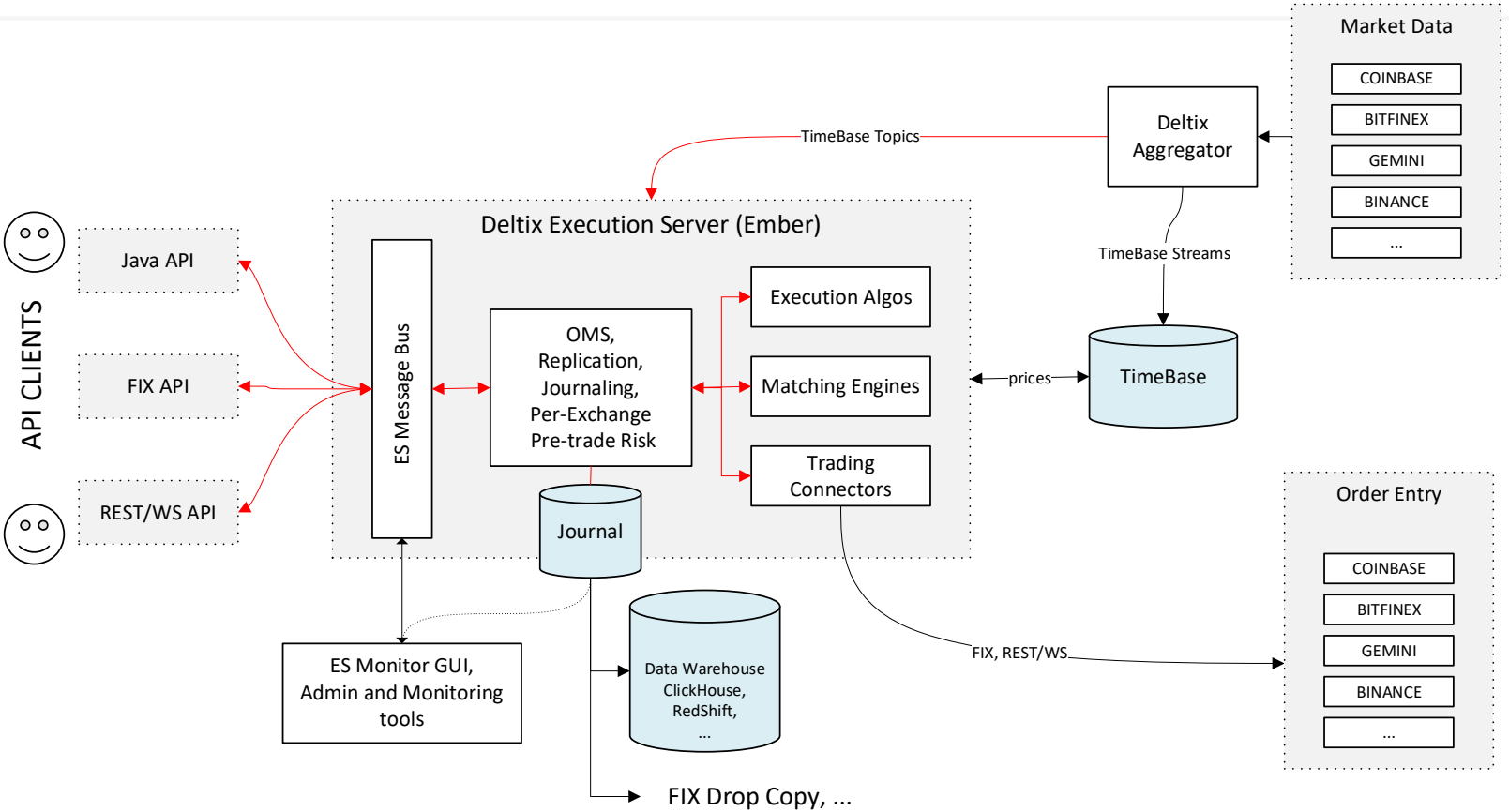
Execution Server (Ember)

Matching Engine / Dark Pool

Deltix Ecosystem Diagram



Ember Architecture



Executable Streaming Prices Workflow

EPAM Matching Engine provides:

- Market-By-Level or Market-By-Order price feed (Level 2 / Level 3)

- Submit/Cancel/Replace Order Entry
  - Mass Cancel
  - Mass Status Request
  - Optional Cancel on Disconnect

Standard Matching Engines (CLOB)

- QuoteFlow = full featured implementation:
  - FIFO (price/time) matching preference, with an ability to customize precedence.
  - MARKET, LIMIT, STOP, STOP_LIMIT, as well as One-Cancel-Other (OCO), One-Updates-Other (OUO), and One-Submit-Other (OSO) order types.
  - FOK, IOC, GTD, GTC time-in-force order conditions.
  - Post-only orders, quantity measured in TERM currency orders.
  - Submit, Cancel, Replace order requests.

- Niagara = easy-to-customize open-source component:
  - FIFO (price/time) matching preference.
  - MARKET, and LIMIT orders types.
  - IOC, GTC time in force order conditions.
  - Submit, Cancel, Replace order requests.

Custom Matching Engines

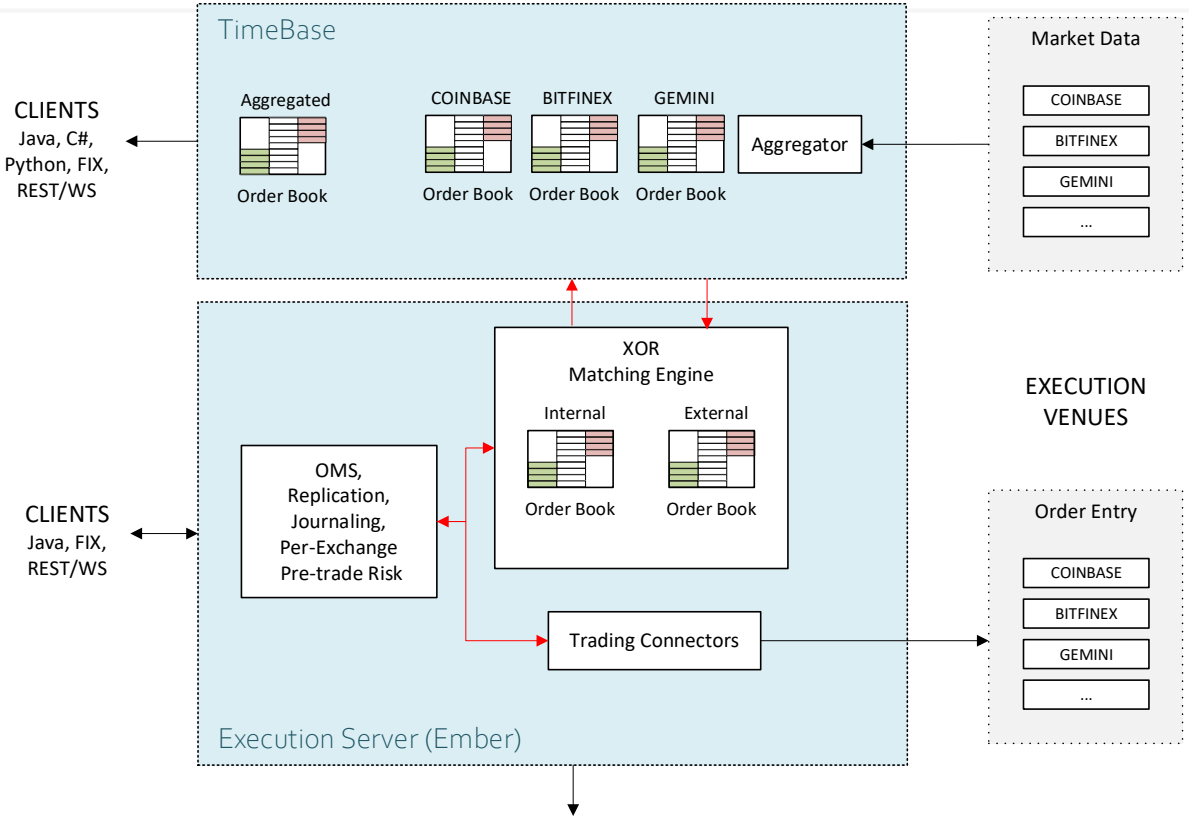
Past successful implementations for various clients

- Dark Pool: Smart Order Routing with Internal Crossing
- Dark Pool: Peg to custom midpoint order matching
- Auto-Deleveraging Matching Engine for Futures Margin Trading
- Regional/Central ECN

Time to market: 2-3 weeks from customer spec to production deployment.

High-Performance Java (up to 200K orders/second Per Contract)

XOR Matching Engine (Smart Order Router with Internal Crossing)



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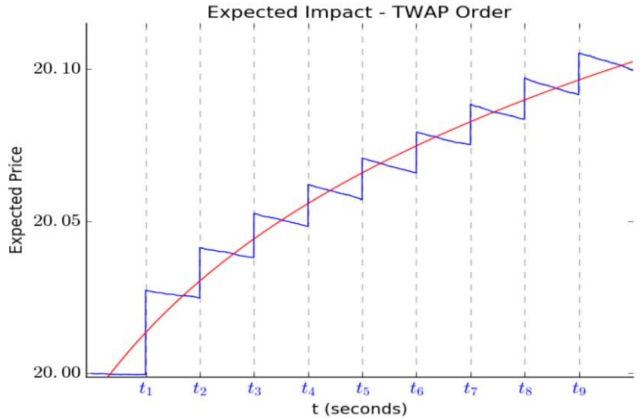
Hedging

- Deltix Market Maker - auto hedging bots
- Tick-to-order latency <10 microseconds
- Connectivity to 150+ execution venues in different asset classes
- Built in execution algorithms (TWAP, VWAP, PVOL, ICEBERG, BRACKET).
- Framework to build custom execution algorithms (15 years of experience)
- Deltix TCA Solution
- QuantOffice Backtesting



Trading Front-end

Trading Front-end: Selected Customization Options

- OpenID Authentication Provider, successful integrations: Auth0, Hydra, Cognito, Gluu
- Logos
- Colors
- Available Widgets
- Available Menu items
- Label Texts
- Internationalization: List of Available Languages
- Custom Footer Text
- Custom Deposit/Withdrawal Text
- Custom Order Entry Text
- Custom Menu Items
- Custom Text for Warnings
- Blockchain Tools Links
- Custom KYC Statuses and Alerts
- “Contact Us” Customization
- Label Texts
- List of Available Layouts 2,3,4 panels
- Custom JWT claim as Trader Display Name
- Hide/Show Advanced View
- Hide/Show Liquidity Origin
- Custom Columns for Instrument Table.

Custom widgets are supported. Special C2 front-end API allows custom widget to sync state/data with the main application.

System-wide pre-trade risk checks

- Order Price/Size Checks
- Long/Short Worst-Case Position Size
- Order Submit Rate
- Order Reject Rate
- Gross Trading Volume
- Max number of open orders
- Max Order Lifetime
- Max Order ACK timeout
- Margin Checks (Spring 2020)

These risk limits can be defined at any projection (Globally, Per-Account, Per-Trader, Per-Exchange, Per-Order Source, Per-Contract, Per-Currency, Per-Product Root). Projections can be composed (e.g. Per-Trader and Exchange).

Per-Trader Risk Limits

- List of Available Instruments
- List of Available Order Types
- List of Available Time In Force
- Trader Balance Checks Including Fees
- Flat / Progressive BASE / TERM Fees
- Loyalty Tokens Fees
- Order Submission Rate
- Price and Quantity Checks
- Markups and Price Customizations
- Max Number of Open Orders
- Max Order Lifetime
- Margin Checks (Spring 2020)


System support custom risk plugins and custom pricing plugins.


Can be defined individually or for hierarchical trader groups.

APIs

Deltix provides the following mass user access APIs for Matching Engine:

- FIX 4.4 Protocol (Market Data and Order Entry)
- Deltix UDP Multicast (Market Data, co-located clients only)
- Deltix proprietary API over TCP/UDP (Order Entry, internal flow only)
- REST/WebSocket API (Market Data, Order Entry, Account Statistics, Personal Settings). Authentication via Open ID and API keys.
- API libraries for custom server-server integrations (Java/.NET)

Administrative APIs

- REST/WebSocket API. Authentication via Open ID and API keys.
- Deltix proprietary API over TCP/UDP
- API libraries for custom server-server integrations (Java/.NET)

Scalability

Matching Engine:

- Partitioned by Instrument, scaled vertically or horizontally

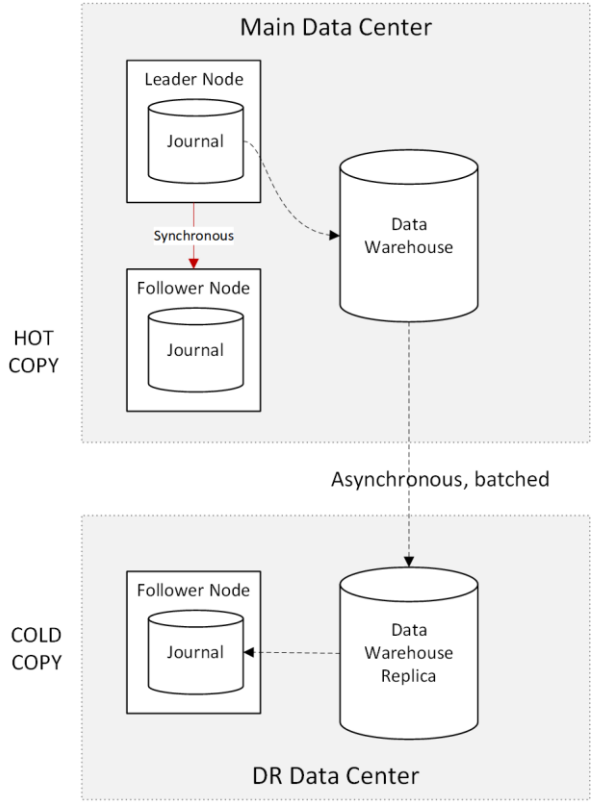
Risk:

- Partitioned per trader group, scaled vertically or horizontally

Failover

No single point of failure

- Active/Passive approach for ME Failover
- Active/Active approach for TN Failover



Some performance numbers:

Throughput

- FIX API Gateway: 120 000 order request/sec
- RPC API Gateway: 210 000 order request/sec

Tick-to-Order

- FIX API: Network packet-to-packet latency:
  median: 9.5 µs, 99P: 25 µs

- RPC API: RTT latency (measured on local client)
  median: 5.1 µs, 99P: 8.9 µs

Monitoring

- Configurator Admin (Operator’s Help Desk)
- Execution Server Monitor (Matching Engine, Algos, External LP Connectivity)
- Integration with Monitoring Systems: Prometheus, Grafana, Zabbix, Graylog, AWS Cloudwatch
- Price Monitoring Tool
- Email / Slack Alert notifications

Hosting

- Kubernetes / Terraform
- Docker/Docker Swarm
- Bare-metal / AWS Cloud / Ansible

What makes us special?

- 10+ years of experience and domain-specific IP
- Architecture that supports high degree of customization (both risk and matching rules) and very short time to market for custom functionality.

- Self-hedging Market Maker
- Modern technology stack, cloud-friendly
- Replicated State Machine approach to matching engine resilience

QUESTIONS?

Secret Sauce

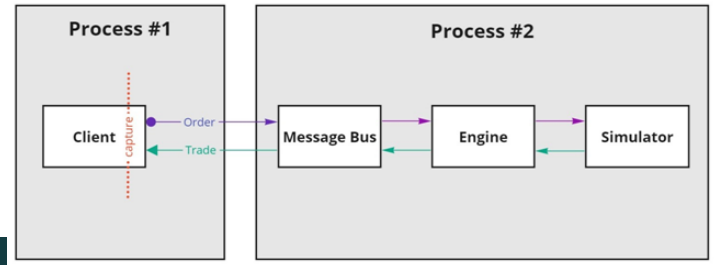
- Lock-free parallelism
- CPU Affinity for critical threads
- Zero memory allocation in hot cycles (No GC pauses)
- In memory state, replicated on cluster, no state sharing between threads
- Non-blocking IO
- Custom DECIMAL64 data type for prices and sizes (wider range than fixed point decimal, better precision than ‘double’). Full IEEE 754 compliant.

Execution Server latency (IPC clients)

RTT Latency (in nanoseconds) depending on Order Request rate

Percentile (%)	1K	10K	50K	100K	200K
0.000	4144	3836	3630	3616	3674
50.000	4783	4359	4191	4187	4211
90.000	7099	4679	4387	4395	4407
99.000	9295	7499	6151	5699	5795
99.900	12535	10463	10263	9735	11255
99.990	15191	13439	13479	16431	15607
99.999	26831	23199	31423	145023	32479
100.000	26831	45855	84735	194687	72511

Round Trip latency for co-located client (shared memory API).
AWS c5.9xlarge instances with CentOS 7.4
No CPU isolation

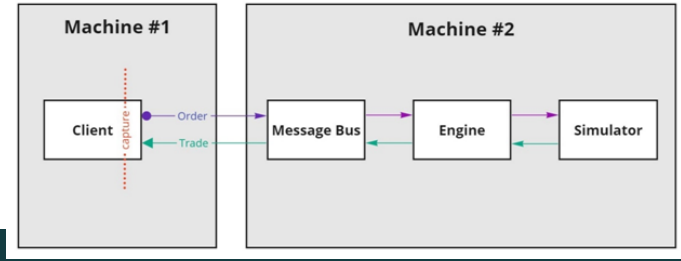


Execution Server latency (UDP clients)

RTT Latency (in nanoseconds) depending on Order Request rate

Percentile (%)	1K	10K	50K	100K	200K
0.000	47040	45632	46464	48896	53344
50.000	52127	50271	60223	76927	71231
90.000	56479	57951	66303	101503	90111
99.000	65343	63231	84031	127679	103743
99.900	95807	89023	100159	153727	134783
99.990	184703	182655	219135	249471	889343
99.999	421887	428543	517119	703999	5390335
100.000	421887	686591	847871	856063	5791743

Round Trip latency for closely-located client (UDP API).
AWS c5.9xlarge instances with CentOS 7.4
No CPU isolation



Tick-To-Order Latency Benchmark

FIX Protocol:
Inbound market data message to outbound order

```
MIN        :         8 (microseconds)
50.0%      :        10
90.0%      :        12
99.0%      :        14
99.9%      :        16
99.99%     :        56
99.999%    :       108
99.9999%   :       277
99.99999%  :       433
99.999999%:       433
MAX        :       433
```

Network packet to packet latency (LIBPCAP)

RPC IPC API: Inbound order to outbound order

```
0.000            3.168 (microseconds)
50.000           5.147
90.000           6.499
99.000           8.935
99.900          10.727
99.990          12.879
99.999          14.791
100.000         17.327
```

Round Trip Time (RTT) measured on IPC API client

Order to Order RTT Latency (TCP Bypass)