White Rabbit in Financial Markets
Time Distribution in Deutsche Börse’s T7® Trading Network
About the speaker

- Degree in computer science from University of Applied Sciences in Darmstadt (1994)
- Working in technology for financial trading since then
- Various roles in two investment banks (Frankfurt, London)
- Performance engineer in a technology-driven trading firm (Amsterdam)

Joined Deutsche Börse in 2016

- Trading IT, monitoring, infrastructure, co-location, and part-time chief cable measurer
- Deutsche Börse operates Xetra, the reference market for exchange trading in German shares and ETFs, and Eurex, a leading global derivatives exchange
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Overview
Obsessed with Time

“The financial industry has easily become the most obsessed with time”

-Balaji Prabakar, Stanford University

“The New York Times

“Time Split to the Nanosecond Is Precisely What Wall Street Wants”

Obsessed with Time

2008

2018
Obsessed with Time
How did this happen?
From trading floor to electronic markets
Central Limit Order Book
Central Limit Order Book (1)

- List of buy orders on the “Bid” side
- List of sell orders on the “Ask” side
- Sorted by price
- Priority on each price level by time
- Price-time priority is the most used electronic execution model

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http://www.boerse-frankfurt.de/webinare-boersenwissen
Example:
We want to buy 100 shares at a price of 73.05
Q: Which of the 5 sell orders is “matched” with our buy order?
A: The sell order which entered the order book the **earliest**.

Implication:
The faster you are, the higher the probability of an order being executed as desired. True for both sides of the trade (buyer and seller)
Matching Algorithms

Price Time

- Priority is determined by price then time
- FIFO queue per price level
- Higher queue priority increases probability of being matched
- The most common matching algorithm
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Asset Prices
Asset Prices

Efficient-market hypothesis: asset prices fully reflect all available information

⇒ New information (events) affect prices

Examples:
- News
- Changes in interest rates
- Release of economic indicators (e.g. unemployment figures)
- The central limit order book of a financial instrument (e.g. stock, bond) itself
- Prices of correlated instruments

Event source can be:
- Remote (send information over WAN)
- Local (LAN, co-location)
Correlated Asset Prices – Example

Euro BUND Future / Euro BOBL Future
T7® Architecture – Price Information

Matching Engine

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<thead>
<tr>
<th>LastTrade</th>
<th>LastVolume</th>
<th>LastPrice</th>
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<tr>
<td>0.30</td>
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<td>73.14</td>
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Prices (A Stream) UDP Multicast

Prices (B Stream) UDP Multicast

Trading Participant
T7® Architecture – Interaction (placing orders)

Matching Engine

Backup

Order Entry Gateway 1
Order Entry Gateway 2
Order Entry Gateway N

Infiniband

Transactions (TCP)

Trading Participant

Deutsche Börse Group
T7® Architecture

Backup

Matching Engine

Prices (A Stream)
UDP Multicast

Prices (B Stream)
UDP Multicast

Infiniband

Order Entry Gateway 1

Order Entry Gateway 2

Order Entry Gateway N

Transactions (TCP)

Trading Participant
T7® Co-location
Zoom in to a single matching engine

Median round-trip from order entry to acknowledgement ≈ 60µs (2) ➔ (7)
The fastest participants have sub 100ns response times (1) ➔ (2)
T7® Co-location

Timestamps
**T7® Co-location**

*Scale (> 500 capture ports, > 60 timestamping devices)*

> 260 Order Entry lines captured (> 500 capture ports)

Identical setup regardless of participant room location and assigned access switch
White Rabbit at Deutsche Börse
White Rabbit in T7® Co-location
60+ timestamping devices in 4 datacentre modules
Networking at an exchange is atypical (bursts)

How do we measure this?

Why do we need something as precise as White Rabbit is?

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T7® Time synchronisation
White Rabbit synchronised timestamps
T7® Time synchronisation
How would we cope with PTP?

From outer network perimeter to order entry gateway
We use White Rabbit

From outer network perimeter to just before order entry gateway

WR time sync is fine

Burst of messages queuing
White Rabbit
Timestamping Devices synchronised by 1PPS
White Rabbit
Timestamping Devices synchronised by 1PPS
Services for our customers
Services for our customers

1. High-Precision Timestamp File (what is my delta to faster competitors)
2. Customer can now synchronise with our WR master
3. Customer can now get UTC from our WR
High Precision Timestamp File

Theoretical minimum (2736 ns)

*Distribution of $t_{3n} - t_9 - \text{median}(t_{9d} - t_9) - \text{median} (t_{3n-t_3a})$ shown

Before (using PTP)
High Precision Timestamp File

Fastest reaction ~ 2820 ns (84 ns net)

After (White Rabbit)

Theoretical minimum (2736 ns)

*Distribution of t_3a – t_9d
Feedback

Normal Operation – Sync error in timestamping devices is less than +/- 1ns
Feedback

Planned work on GPS receiver on a Saturday
GPS service was restored by 11:00 (yellow bar)
Conclusion
Conclusion

We have reached our goal of sub 10ns synchronisation of all capture devices.

We realize that we are not using all of White Rabbit’s features. Essentially, we use it to distribute 1PPS over fibre optic cables. We look forward to having more vendor support for White Rabbit in the future. This would enable full end-to-end White Rabbit time distribution.

We are confident enough to provide White Rabbit based services to real, paying customers.

We would like to thank the White Rabbit project and community for all their hard work.

Also, many thanks to Cesar Prados and Ralph Baer at GSI for giving us our first White Rabbit demonstration.
Thank you for your attention

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andreas.lohr@deutsche-boerse.com
Matching Algorithms

Pro Rata

- Priority is determined by price and proportionate to the total volume on the price level
- Used in some option markets (e.g. USA)

Matching Algorithms
Measures to Reduce Need for Speed

Actual

- Various “Speed Bumps”
  - Magic shoe box = long box of coiled up cable
  - “Latency floor”

- Last Look
  - Liquidity provider has additional time to device whether to accept a trade or not
  - Used in foreign exchange markets (currencies)

- Passive Liquidity Protection on Eurex
  - New orders that could match with resting orders in the limit order book will be deferred
  - For options
Matching Algorithms
Measures to Reduce Need for Speed

Proposals

- Frequent Batch Auctions
  - https://faculty.chicagobooth.edu/eric.budish/research/HFT-FrequentBatchAuctions.pdf
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