CS 349F: Technologies for Financial Systems

Instructors: Balaji Prabhatkar and Mendel Rosenblum
CA: Ahmad Ghalayini
Course Logistics

Course website: http://web.stanford.edu/class/cs349f/
- Has all the latest course info, including handouts and reading materials
- Class mailing list: cs349f-aut2021-staff@lists.stanford.edu

Off hours: For the first week; later meetings TBC
- Prabhakar: Tue, 11am—12pm (TBC)
- Rosenblum: Mon, 1—2pm (TBC)

Grading basis: S/NC (Pass/Fail); to get an S, you need
1. Attendance in 15 out of 20 lectures (determined by Canvas/Zoom)
2. Participate in the algorithmic trading sessions in weeks 7—9
   - Trading hours: 7—9pm on Mon/Tue/Wed in the weeks of Oct 26th, Nov 2nd and Nov 9th
3. A 2-page report by 5pm, Nov 20th, 2020 (details will be emailed in advance)

Special guest lecture on Wed, Oct 7th at 4pm, PST
Outgrowth of our multi-year research program on Self-Programming Networks

Coming together of 3 major technologies

- **Networking**: Protocols/Systems for machines to communicate with each other
- **Distributed Computing**: Protocols/Systems for machines to compute/store data
- **Electronic Financial Trading**: Rules/Protocols/Methods for machines to trust and trade with each other

Let’s look at each of these briefly
Self-Programming Networks

SPN is a 4 year old research program

- Co-PIs: BP and Mendel Rosenblum (OS, virtualization, web applications)
- It supports the research of several PhD students and postdocs
- And we work with a number of industry collaborators

Research goal: A quest to make networks

- **autonomous**: network should sense and monitor itself; program and control itself
- **interactive**: network should be simple and fun to use, especially for 3rd party users
SPN is a research module of the Platform Lab @ Stanford

Bill Dally
Architecture

Sachin Katti
Networking

Christos Kozyrakis
Architecture, System Software

Phil Levis
Embedded Systems

Nick McKeown
Networking

John Ousterhout
Granular Computing (Fac. Director)

Guru Parulkar
Networking (Exec. Director)

Balaji Prabhakar
Networking

Mendel Rosenblum
Distributed Systems, Networking

Keith Winstein
Networking, Granular Apps

Matei Zaharia
Big Data, Cloud Computing
SPN Sponsors

- Google
- Cisco
- Broadcom
- VMware
- Intel
- SGX
- Wells Fargo
- Nasdaq
Plain Old Data Center

Workload

App

App

App
Self-Programming Network (SPN)

Plain Old Data Center

- Sense, Infer, Learn and Control (SILC)
- Interactive Dashboard & Query Engine
- Intuitive DB and QE
  - Simple + visual + chatty
  - App+network perf views
- NIC- or Edge-centric Approach
  - Sensing and control at NICs
  - Smart NICs: big industry trend
- Data and ML Intensive
  - Use data and NNs to accelerate learning and for real-time processing

Workload → Sense, Control

App → Sense, Infer, Learn and Control (SILC)
Network Telemetry From The Edge: Tomography

From total time in the network, determine time spent in each switch

Clock Synchronization

TX Timestamp

RX Timestamp
A Timeline of Networking, Computing and Trading Technologies

Networking:
- 1876: Telephony
- 1960s: Packet Switching Invented
- NOW: Data Centers

Computing:
- 1920s: Monolithic Architecture
- 1970s: Distributed, Cluster Computing
- NOW: Internet, Mobile

Financial Trading:
- 1856: Used Telegraph
- 1876: Used Telephony
- 1960s: Used Computerized Market Data Feed
- 1971: NASDAQ: Electronic Trading
- NOW: Financial Trading: Fully Electronic

FUTURE: Financial Trading in The Cloud
Key Takeaways

1. Financial trading has **always adopted bleeding edge** technology
   a. For getting the **latest** information
   b. For getting the **fastest** trading and matching algorithms
   c. Not to mention methodologies like Statistical Inference and Computational Math

2. It has significantly impacted the development of these technologies and products
   • Especially in the low latency and high-speed dimensions

3. Now, it wants to
   • **Scale:** To large numbers of market participant and domains (not just stocks, currencies, etc)
   • **Use AI:** For everything from fraud detection, market surveillance to developing trading strategies
     ➔ Both these aims align well with moving financial trading exchanges to the Cloud

➔ In this course we will see the challenges and opportunities involved in moving financial exchanges to the Cloud
We will start by understanding the technological requirements of trading exchanges and how to build an exchange in the cloud
A Brief History of Financial Trading

People have been trading forever; however, some noteworthy milestones...

• 1100s—1200s: France, courretiers de change, managed agricultural debt (by trading it)
• 1300s: “Merchants of Venice”, Florence, Genoa, etc: Trading government securities (bonds)
• 1400s—1500s: First “stock” markets: Belgium (Antwerp), Rotterdam, Flanders, Netherlands

1600s: Financial Exchanges

• Trading venues for financial securities; e.g., equities (stocks), commodities, futures, bonds
• Early examples: Amsterdam Stock Exchange (1602), NY Stock Exchange (derived from the Buttonwood Agreement in 1792), Paris Stock Exchange (1801), London Stock Exchange (early 1800s), Chicago Mercantile Exchange (1874)

Trading Protocol: The Open Outcry

• Bids and offers verbally shouted out, resulting in matching of buyers and sellers
The Role of Technology in Financial Trading

1832: Telegraph and Morse code invented
1856: Broker-assisted trading via telegraph
1867: Edward Calahan invents the “stock ticker” to disseminate up-to-the-minute NYSE stock quotes nationally

1876: Telephone invented; enabled trading over phone from remote market participants

1960s: Computerized digital stock quote delivery system provides market data “on demand” rather than cyclically like the ticker tape

1969: Instinet develops the first fully automated system for trading securities electronically for large institutional investors

1971: NASDAQ creates fully automated trading exchange: market participants could connect and trade with exchange electronically (modems)

Now: Open outcry eliminated in most major exchanges; trading is fully electronic

To a first order approximation, financial trading can be broken into two main computational loops

1. Fast loop: At trading venues like NYSE, NASDAQ, CME, etc
2. Slow loop: When a market participant runs large-scale computations on market data to devise their trading strategies or algorithms

Key concept that comes up in modern financial trading is high frequency trading (HFT)

- Some people think this is bad since HF is not required for discovering prices or for providing liquidity
- Others (including some amongst the regulators) think it does make the market more efficient
- Related concept: arbitrage
Pros and Cons of Electronic Trading

Proponents’ view
- Greater liquidity
- Lower commissions and fees
- Ease of market access
- Tighter bid/ask spreads

Criticisms
- Enhanced market volatility
- Susceptibility to technology failure
- Lack of transparency
- Ease of market manipulation

We will have to bear this in mind
- As financial trading makes the next big leap into Cloud and using AI techniques: new technology invariably introduces pros/cons

The Architecture of Financial Trading Exchanges: Two Computation Loops
Fast Loop: Orders ↔ Market Data

- *At exchanges and trading venues in real-time*
- **Low latency is critical:**
  - FPGAs perform trades at great speed, bring determinism
  - network is carefully engineered to *eliminate jitter*
  - excess bandwidth and compute power ensure low latency
Slow Loop or Training Mode: Market Data ↔ Trading Strategies and Algorithms

- **In large-scale compute clusters**
- **Accurate market data capture and playback:** Relies on high-precision timestamping of market feeds
- **Large-scale computation and ML/ AI tools needed:** Where Cloud computing has an edge, but oftentimes market data is in the exchange colocation facility, not in the Cloud
In the Near Future...

Exchanges Move Into The Cloud and AI Enables Self-driving Trading Systems
Arguments in favor

1. Physical space is restricted at co-location facilities; hence, cannot support data storage/processing servers as well → Cloud is elastic
2. Financial firms better off outsourcing infra to cloud and focus on their core strength, instead
3. Can support many more types of exchanges than just financial exchanges → Imagine a world where most commerce is conducted via auctions; i.e., end of fixed prices

Think of critical infrastructure, and sectors such as telecommunications, agriculture, and construction likely come to mind, as physical assets such as networks, farms, roads, and bridges keep economies humming. But the financial services industry is also among this cohort, according to the Department of Homeland Security. As such, the onus is on the sector to invest in the future well-being of our economy. After all, well-functioning markets connect companies and people to the capital, information, and technology they need to foster innovation, generate more jobs, and drive GDP growth worldwide.

Market infrastructure is the backbone that hosts the life cycle of every transaction. It was tested in March when, due to the COVID-19 pandemic, volatility surged and
Both Loops In the Cloud + Trading Algos Developed by AI
Rest of the Lectures

• Requirements of Financial Exchanges: fairness and low-latency
  • Guest lectures by Deutsche-Borse and Cisco (ExaBlaze)

• Networking and Cloud Computing basics

• Accurate clock synchronization and its uses
  • Network telemetry
  • Congestion control

• How stock exchanges and trading work
  • Guest lectures by Nasdaq, Dean of Columbia Business School, Goldman-Sachs

• CloudEx: Intro, deep dive, trading competition

• Guest lectures on other trading systems (Commodities, ForEx, AdTech)