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Nasdaq Decodes:
Tech Trends 2021

THE TECHNOLOGY TRENDS THAT ARE DRIVING THE WORLD OF MARKETS FORWARD

Foreword

COVID-19 rocked our world in 2020, accelerating societal and technological changes at a pace we never imagined. Just a few weeks after the start of the year, countries around the world were in lockdown, and most businesses rapidly shifted their operations to remote work environments.

Market volatility and volumes soared. Nasdaq hit several records across its markets in the first half of 2020. The options market had its 10 most active days ever, peaking at about 62 billion messages in a single day. The U.S. equities market had its highest volume day since 2009, peaking at about 5 billion messages, which was about two times its previous all-time high. Additionally, Nasdaq and other industry market operators invoked four market-wide halt events for the first time ever, working as expected with the markets pausing and returning to normal operations in an orderly manner. With the combination of excellent technology and a dedicated workforce, Nasdaq accomplished this with almost all staff working remotely.

2021 is the fifth consecutive year that we are publishing a report on the technology trends that we believe are having the most impact on our industry, and our outlook for the year ahead. The events of 2020 demonstrate the importance of maintaining resiliency, capacity, performance, immediacy and security across our businesses. Appropriately, the focus of this year's Nasdaq Decodes report is on the technologies and recent innovations that build, drive and support operational excellence.

In this report, we would like to highlight the four key trends that are reflected in our priorities:

First, systems on chips (SoCs) and field-programmable gate arrays (FPGAs) are not new, but recent innovations in this space excite us. Notably, we are seeing the rise of Advanced RISC Machine (ARM) architecture for central processing units (CPUs) and advancements in graphics processing units (GPUs) and machine learning optimized chips. These innovations allow us to build more efficient trading systems, deliver better performance, reduce complexity, lower the cost of end products, increase profitability and add new features that differentiate our products. These innovations are having a profound impact on our business – and the financial services industry as a whole – especially as the industry migrates to the cloud.

Second, edge cloud is reducing reliance on centralized processing (processing performed in one computer or in a cluster of coupled computers in a single location), bringing greater scale and performance to consumers in an increasingly connected world. We see myriad practical use cases outside of financial services such as in internet of things (IoT), vehicular applications and drone applications. In the financial services industry, edge cloud can support workflows designed to evolve customer engagement models and provide deeper insights from data, as well as enable hybrid cloud strategies.

Third, the powerful combination of cloud, federated learning and homomorphic encryption could potentially overcome regulatory and other barriers to sharing and analyzing data for purposes such as fighting financial crime and improving market integrity. The cloud is a neutral, secure infrastructure for internal and external stakeholders to share, analyze and act upon data, and the hyperscale cloud providers have tools to help organizations do it. With federated learning, organizations can share insights without actually sharing data. Moreover, homomorphic encryption is emerging as a technology that can allow organizations to share data, retain complete control over who can access or perform analysis on that data, and own auditability of that process.

Fourth, the adoption of the software-as-a-service model (SaaS) in the cloud is rapidly accelerating. Financial institutions and marketplaces are finding that SaaS makes it much faster and cost effective to onboard clients and upgrade and deliver new products. SaaS in the cloud contributes to our resiliency and security because it alleviates some of the potential risk of downtime in our own data centers. Deploying infrastructure as code allows us to manage and define the desired state of our technology infrastructure using configuration files, and determine the security configuration before it is deployed in a public cloud.

Given the opportunities presented by these technology trends, we are pleased to offer you our view on the current state of technology in the capital markets and beyond. At Nasdaq, we work with these technologies every day; they energize us and keep us focused on our path forward into an exciting future.

Four Key Trends:

1. Recent Innovations in SoCs & FPGAs
2. Edge Cloud Reducing Reliance on Centralized Processing
3. Powerful Combination of Cloud, Federated Learning and Homomorphic Encryption
4. Accelerated Adoption of SaaS and Cloud

62B

messages per day in 2020 Nasdaq Options Market

5B

messages in one day highest volume day since 2009 Nasdaq US Equities Market

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Custom Chips Are Key to Next Generation Compute

Systems on chips (SoCs) are not new, but recent innovations in this space are affecting Nasdaq's business – and the financial services industry as a whole – especially as we and the industry migrate to the cloud. Essentially, these advancements are giving us the tools and flexibility to design faster, more efficient and more resilient trading systems.

SoCs combine many separate components previously spread across a computer's motherboard – such as processors, graphics processing units (GPUs), memory, network and input/output channels – into a single, custom chip the same size or smaller than a conventional CPU. Many SoCs deliver efficient performance partially because their CPUs use the ARM architecture, which runs a smaller, simpler instruction set. ARM has primarily been used in consumer products such as mobile phones, tablets and other systems with size and power constraints. Today, SoCs with ARM architecture power many IoT-enabling devices such as laptops, smartphones, smart gadgets, smart watches, and smart and autonomous vehicles. The demand for ARM is also being driven by the growing adoption in robotics and investment in smart cities.

Currently, a matching engine cannot be moved to an ARM CPU architecture because it does not meet an exchange's specific performance needs. That said, many Java workloads work well on ARM, especially with recent advancements in ARM support in the Java Virtual Machine. The architecture makes sense for trading applications as well, although more maturity is needed in these systems and for ARM-based systems attached to network cards that support multicast and other required specialized performance features.

In addition, we can take advantage of ARM in a cloud environment. Amazon Web Services (AWS) uses ARM in some ancillary hardware on its machines. It now offers a server that is built entirely on ARM instead of an Intel or AMD CPU, and it is building a data warehouse tool based on ARM CPUs. All of Apple's hardware is going to switch to Apple's ARM-based CPUs over the next 18-24 months as well. This is relevant for the financial services industry because SoCs and ARM architecture enable cloud providers to offer bare metal servers – servers entirely dedicated to a single customer with no virtualization layer between applications and hardware. Running our applications directly on the hardware allows us to process data faster and retain direct control over what is running on the system.

It is notable that custom hardware is advancing the development of machine learning and AI-optimized chips. Google was a pioneer in this space with its custom machine learning hardware known as the Tensor Processing Unit (TPU). Similarly, AWS released Inferentia, a custom piece of silicon that is meant for machine learning workloads.

There have been important developments in the GPU space as well. Nvidia's GPUs were invented to produce realistic video game graphics, but they are also highly suitable for training neural networks in machine learning and artificial intelligence. Nvidia's GPU chips are getting much faster, especially with the recent launch of its Ampere lineup. Further, the hyperscale cloud providers plan to install the new chips in their servers. Financial institutions have adopted Nvidia's GPUs because of their ability to deliver fast analytics in areas such as artificial intelligence, fraud analysis, risk management and algorithmic trading.

The ability to have more cores per chip and smaller, faster and more power-efficient transistors is enabling synergies between the different types of CPUs and FPGAs. FPGAs contain integrated circuits designed to be physically changed and customized by the client or designer after manufacturing, allowing the creation of systems more flexible and deterministic than CPU-only solutions. Tighter integration of CPUs and FPGAs on a single piece of silicon allows components to communicate faster, resulting in lower latency and better performance.

Further, industry consolidation is allowing greater synergies between the CPU, the FPGAs' logic and the GPUs. Specifically, Intel acquired Altera, and AMD is acquiring Xilinx, which in turn purchased network hardware manufacturer SolarFlare. Xilinx recently released a product that includes a SolarFlare chip and a Xilinx chip on the same board. Xilinx is also working on heterogeneous compute, where systems use more than one kind of processor or cores. The company plans to build a type of computing platform that will lead to faster system response and higher throughput and allow developers to specify which logic goes to CPUs, GPUs and FPGAs.

In other developments, some FPGA chips include ARM cores, allowing for parallel processing in FPGA and sequential processing on an ARM. FPGAs have become more approachable for software developers. With high-level synthesis tools, developers can write code in a C-like language, and then generate the logic for the FPGA. Some products have been released in this space, including Xilinx's Alveo lineup. Nvidia offers CUDA, a specific API for programing GPUs. Moreover, Intel is gaining traction with Intel oneAPI, which allows developers to write code once, and then target many processing resources including CPUs, GPUs, FPGAs and artificial intelligence engines.

All of these innovations allow us to build more efficient trading systems, deliver better performance, reduce complexity, lower the cost of end products, increase profitability and add new features that differentiate our products.

We can take advantage of modern cloud infrastructure and translate what we have done on-premise into a design that works and brings resiliency to the cloud. Ultimately, this is good for our clients and the capital markets as a whole.

Advancements with SoCs give us the tools and flexibility to design faster, more efficient and more resilient trading systems.

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Edge Cloud is Bringing Greater Scale and Performance to Consumers

An enormous amount of data is being generated, processed and consumed by many types of devices and IoT, further enabled by modern 5G networks. **Edge cloud is a dynamic and distributed cloud model where compute and storage resources move close to the edge of the network; the edge of the network is where content is created and consumed.** Edge cloud reduces reliance on centralized processing, bringing greater scale and performance to consumers in an increasingly connected world.

Often data needs to be collected on remote devices and in tight spaces where portability is necessary or connectivity is unreliable. Examples include on offshore oil rigs, in first responders' backpacks, or in IoT, vehicular and drone use cases. To this end, the hyperscale cloud providers have designed edge-computing, data-migration and edge-storage devices to be used in these types of environments to ensure data gets to where it needs to go faster, more reliably and more securely. AWS' tiered offering comprises large regions, Local Zones, Outposts, Wavelength Zones, Snowball Edge and Snowcone. In addition, Microsoft has launched Azure Edge Zones and Private Edge Zones.

At Nasdaq, we see myriad practical use cases for edge cloud. Data can be collected from sensors in roadways and traffic lights to gauge traffic flow and price tolls dynamically. It can be collected from machines in a factory, and then sent to a nearby location for analysis to determine when the device is likely to fail or need maintenance. An aircraft engine manufacturer can retrieve specific metrics in flight, and then do the bulk downloads of telemetry data at the airport gate. Pharmaceutical companies can instrument their vaccine shipments so they receive an alert if the temperature deviates from the correct parameters – a critical use case in the age of COVID-19.

There are also many applications for edge cloud in financial services. Essentially, marketplaces and financial firms can create a special purpose or customized cloud that is aimed at addressing the needs of certain workflows. Retail banks can use edge cloud to enhance their client experience on apps, tablets and kiosks. Investment managers can use low-latency edge computing to make predictions with machine learning models trained in the public cloud using alternative datasets such as satellite imagery showing crop yields, oil reserves and retail parking lot usage. This allows them to gain insight into the macro economy, as well as specific sectors and companies. New, emerging marketplaces could leverage edge cloud to run their matching engines as well. The list goes on.

Finally, edge cloud could play a role in a hybrid cloud strategy. Our clients – marketplaces and financial firms – could interact in the cloud at the edge while maintaining their existing connectivity in the data center. Once issues around latency, determinism, and throughput are solved in a virtualized environment and more advancements have been made in multicast and software-defined network solutions, clients can transition to the cloud service facility that is owned and operated by the provider.

Cloud and New Technologies Are Allowing Data Sharing Without Violating Privacy Regulations

Data sharing provides opportunities for marketplaces and financial institutions to create new product and service offerings, break institutional silos and enable safer, more efficient markets.

However, data is a source of competitive intelligence, so financial institutions are naturally reluctant to share it. Besides, they have a mandate to comply with stringent data protection and privacy regulations such as GDPR in Europe. As a result, it is difficult to decide where the data is going to be stored and how it is going to be processed.

> **The cloud combined with emerging technologies such as federated learning, homomorphic encryption and sensible regulation could overcome the barriers to sharing and analyzing data for the benefit of the industry and society while maintaining privacy.**

The cloud is a neutral, secure infrastructure for internal and external stakeholders to share, analyze and act upon data, and the hyperscale cloud providers have tools to help organizations do it. These tools allow users that have access to shared data to always see the most up-to-date and consistent information as it is updated in the data warehouse. Users can find, subscribe to and use third-party data in the cloud. Data can be shared in any format and size from multiple sources.

Trust is the vehicle for facilitating data, but we must assume zero trust – that is, there is no trusted compute, so we have to harden and encrypt all data. Multiple new technologies could allow us to do that.

The first technology is federated learning, which enables us to share insights without actually sharing data or storing user data in the cloud. Essentially, a model is trained across multiple datasets without ever bringing the data together or looking at personal information. Google is using

Edge cloud reduces reliance on centralized processing, bringing greater scale and performance to consumers in an increasingly connected world.

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federated learning in Gboard on Android, the Google Keyboard. According to Google, a person's device downloads the current model, improves it by learning from data on the phone, and then summarizes the changes as a small focused update. Only the update to the model is sent to the cloud, using encrypted communication, where it is immediately averaged with other user updates to improve the shared model. All the training data remains on the device, and no individual updates are stored in the cloud.

The second technology is homomorphic encryption. Organizations can share data, retain complete control over who can access or perform analysis on that data at a granular level, and own auditability of that process. It cannot be leaked or accessed outside the bounds of what is permissible, so it changes the way in which privacy regulations can be applied in practice.

Homomorphic encryption is emerging, but it is not ready for production. Because of the way the cypher is constructed, a few bytes will turn into many megabytes, which is not practical at scale today, and the calculations are quite slow.

> **Homomorphic Encryption: Organizations can share data, retain complete control over who can access or perform analysis on that data at a granular level, and own auditability of that process.**

That said, a lot of research and innovation is happening in this space. **Nasdaq is currently working with Intel on a hardware acceleration of the homomorphic encryption calculations to get a 100x improvement in speed in early 2021.** Moreover, MIT's Secure Cyber Risk Aggregation and Measurement (SCRAM) is using homomorphic encryption to provide a security benchmarking platform for sharing vulnerability and hacking information without exposing who the organizations are, or the details of the attack. The goal is to identify trends, vulnerabilities and active exploits at a broader scale than any one organization can do alone. This technology will likely mature quite rapidly, and in a few years we could start to see live, deployed solutions.

These technologies for secure data sharing can help us solve problems and add value for our clients. To illustrate, Nasdaq offers various services in the cloud, including trade surveillance. Our clients' data is segregated, but we gain insights by analyzing the aggregated data pertaining to how clients use our systems. We then share this information with our clients in peer group reports. In post-trade, aggregated clearing data could be analyzed and shared to improve risk management and make better decisions about margining and collateral utilization, and aggregated CSD data could add value for issuers.

We see tremendous potential to leverage these technologies in the fight against financial crime – including money laundering, fraud, terrorist financing and human trafficking – which is often executed across multiple institutions. For example, solution provider Verafin has a cloud-based infrastructure for sharing and modeling data on certain behaviors without compromising trust and data privacy. Verafin sends alerts to its bank customers when unusual transactions occur, and then facilitates data sharing and joint data investigations to fully scrutinize the behavior. In addition, Verafin performs data analytics across all clients' data to deliver insights that ultimately improve the detection accuracy for its customers.

In reality, unless there is a regulatory framework for sharing data, financial institutions are unlikely to take full advantage of it. In our view, the USA Patriot Act Section 314(b) could be a model for other regions. Section 314(b) permits financial institutions, upon providing notice to the U.S. Department of the Treasury, to share information with one another in order to identify and report activities that may involve money laundering or terrorist activity to the federal government.

Innovations such as federated learning and homomorphic encryption will drive the inefficiency of computing on encrypted data down to a level that unlocks new capabilities, even if it cannot be fully eliminated. Combined with the tools offered by the cloud providers, these innovations will help to chip away at concerns around data usage, privacy and auditing. This approach can drive customer insights, generate revenue and help us solve important business problems, such as financial crime and cyberattacks. Everybody working alone will never be as good as everybody working together. Similarly, we need to bring the data together to look at the big picture - if we can accomplish that, it will make our industry far more resilient than it is today.

SaaS in the Cloud and Infrastructure as Code Are Boosting Efficiency and Security

SaaS empowers technology providers to utilize their underlying infrastructure to onboard clients, respond to changes in client engagement, upgrade products, deliver new products faster and achieve scale. Moreover, APIs give SaaS providers the flexibility and capability to innovate beyond the basic user experience.

> **SaaS providers' clients benefit because they can focus on their business instead of focusing on frameworks, infrastructure, applications and service.**

Innovations such as federated learning and homomorphic encryption will drive the inefficiency of computing on encrypted data down to a level that unlocks new capabilities, even if it cannot be fully eliminated.

100x

Improvement in Speed in 2021 Nasdaq & Intel's Hardware Accelaration of Homomorphic Encryption Calculations

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SaaS in the cloud is an even more compelling proposition. Clients pay per use, so they have more agility in terms of managing costs, and they can potentially pass the savings onto their end users. Pricing is more granular as well; when clients purchase hardware for their data center, there is a five- or seven-year depreciation. In the cloud, that cost is driven to per-minute or per-second pricing and usage. Imagine paying only by the seconds the service is in use instead of paying by year-long subscriptions.

Given the benefits, many technology providers are successfully adopting the SaaS model. To illustrate, Splunk releases new software every six weeks, so its clients always have the latest version, enabling clients to focus on their core business activities instead of on keeping software and infrastructure up and running. The company's cloud clients have a 57% faster time to value, and a 47% improvement in their customer health score, which tracks several aspects of value. Splunk created Autobahn, which is a SaaS proof-of-value program that allows its clients to try the cloud for a specific use case. More than 80% of them convert that use case to the cloud after the trial.

Remote working during COVID-19 has presented many unique challenges, but SaaS in the cloud allowed Zscaler to rapidly scale its secure web gateway to its many clients across the globe. The pandemic also opened the door to new forms of financial crime, but SaaS in the cloud enabled Verafin to detect unusual transaction patterns and send alerts quickly to its financial institution clients.

Nasdaq has adopted the SaaS model for several of our offerings. Among them is our cloud-based Marketplace Services Platform, which provides access to services covering the entire transaction lifecycle – from issuance of assets and trading through pre-trade risk management, market surveillance, digital custody and settlement. From Nasdaq's and our clients' perspective, security is top of mind. The SaaS model enables us to resolve potential security bugs and vulnerabilities much faster than previously possible with other deployment models. A SaaS deployment model allows us to fix once and affect many clients, whereas in a traditional deployment model, we would need to patch each client instance or provide clients with an artifact to deploy the patch. The concept of being able to fix an issue once and impact many is a force multiplier for our security team when they are maintaining SaaS applications.

SaaS in the cloud is not only more cost effective for us, but it also adds another layer of resiliency and security. The hyperscale cloud providers upgrade and improve their technology continuously and have the economies of scale to offer services that traditional data center providers cannot. Our risk is reduced because we are less likely to experience downtime due to an incident in our own data center. In addition, the cloud providers understand and support local regulations, which is important for us because we operate in multiple jurisdictions.

Further efficiencies have been gained by using infrastructure as code in the cloud environment. Manual configuration is resource intensive and costly. It is also slow and error prone, which impacts scalability, availability, and frequently leads to inconsistencies in how resources are configured. With infrastructure as code, we can manage and define the desired state of our technology infrastructure – including servers, applications and networks – using configuration files. We can deploy infrastructure quickly and consistently by running a set of scripts, therefore improving efficiency in our software development lifecycle. The same configuration files can be deployed repeatedly, which eliminates inconsistencies, and all changes are traceable and auditable. The fact that SaaS is code and API driven gives us more control from a security perspective. We use tools to perform static analysis of infrastructure as code and determine the security configuration before it is deployed in a public cloud, allowing responsibility to be "shifted left" or earlier in the development process, so the required level of security and governance is designed into our applications. Adoption of infrastructure as code, and the tooling to support it, allows smaller teams to have greater impact on our organization and allows Nasdaq to take an important step in our cloud journey.

Admittedly, transforming from enterprise delivery to SaaS is a challenging journey. Implementing different technology is only part of the process; the other part is a culture, mindset, and organizational change that requires top-down alignment. The transformation process affects the whole ecosystem, including the way products are sold and customized, as well as how costs are managed. Another headwind is the ability to hire staff with the right skills and expertise in both information security and cloud deployments. However, the upside far outweighs the downside.

> **Through SaaS transformation, we can scale our business quicker, and deliver better and more flexible products and services to our clients.**

Conclusion

The global pandemic has tested our mettle. In addition to coping with huge volumes and volatility on our exchanges, we have been challenged to manage a remote workforce and engage with clients across the globe facing their own struggles. Our accomplishments during 2020 reflect our resiliency. Our technology strategy – which includes moving to the cloud – is robust, and we are committed to it.

Going forward, we see an opportunity to leverage innovations in SoCs, edge cloud, machine learning and encryption techniques, as well as SaaS to make us even stronger and more agile. Not only will these innovations equip us to deliver top quality products and services to our customers, but they will position us to adapt to changing business environments.

> **In 2021, we will continue to invent, innovate and improve our core products that are already powering over 300 marketplaces and participants globally.**

In addition, we will continue to look toward other industries for fresh ideas on how to leverage technology to advance our business and our industry.

Splunk's cloud clients have a 57% faster time to value and a 47% improvement in customer health score.

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