# DECENTRALIZED INNOVATION

## Approach to Building Multilateral Collaborations in Science and Technology

T. Charles Clancy, PhD – The MITRE Corporation
Sriram Viswanath, PhD – The MITRE Corporation & University of Texas, Austin

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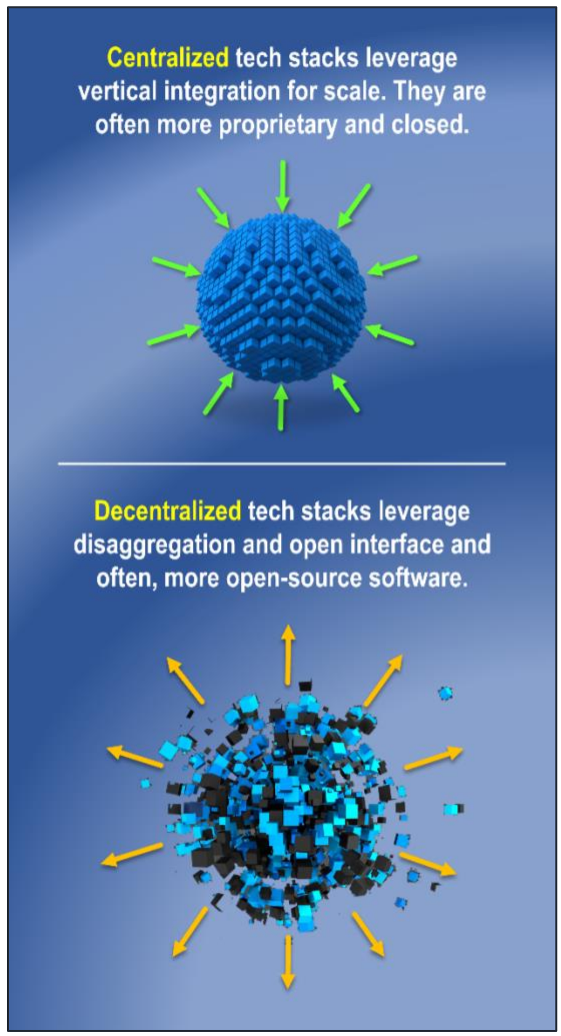
## Introduction

Technology tends to oscillate between centralized and decentralized architectures, depending on the technical problems of the era. The internet began very decentralized, but funding the infrastructure and scale needed to effectively monetize it required centralization in a few hyperscalers. Software systems, on the other hand, have swung in the opposite direction, starting with big, monolithic code bases, and evolving to decentralized open-source projects and cloud microservices. The Web3 phenomenon has sought to decentralize a wide range of digital assets and services, with mixed results.

This push-and-pull has been evident in software for decades, and can be exemplified by, for example, the difference between the Apple and Android mobile ecosystems.[1] However here we consider a broader mental model not only applicable to the technology systems themselves, but the innovation process that creates them in the first place. **Our thesis is that decentralized innovation yields inherently democratic technologies.**

China's approach to innovation uniquely benefits from centralized technology stacks. Their system of top-down, state-directed investments through national industrial champions favors vertical integration. Autocracy also benefits from technology stacks that can be centrally controlled and monitored.

Much of the discussion about Western techno-economic competition with China has focused on instilling democratic values in technologies as a core tenet of the current resurgence of science and technology (S&T) investment across the United States (U.S.) and its allies. However, until now, how this tenet translates into specific policies has been unclear. In this paper, we propose that decentralization offers a way to deliver on democratic values while also uniquely enabling both domestic and international innovation systems to flourish.



## Decentralization as a Technology Strategy

Although the precise mechanization varies across different technology domains, decentralization is the underlying notion that technologies should be disaggregated, avoid the presumption of vertical integration, and allow smaller innovators to plug in their components without significant barriers to entry.

Fundamentally, decentralization enables a few core objectives:

- **Free Market:** Decentralization allows for innovators like universities and startups to build components, rather than having to build the entire system, thus reducing market barriers to entry, creating on-ramps for new ideas and solutions, and fostering diversity in the supply chain.

- **Multilateral:** Decentralization allows for distributed national investment and loosely coupled international investment in research and development (R&D) to have built-in paths to technology transition and integration into larger systems.

- **Anti-Authoritarian:** Decentralization allows for security, privacy, and respect for civil liberties by creating component-level transparency in systems rather than vertically integrated black boxes. It can also create conditions for users to own and control their own data, increasing privacy and agency.

One example of decentralization is Open Radio Access Network (O-RAN) technology. Building wireless base station equipment that runs cell towers has become increasingly complex. Individual vendors have built their own proprietary architecture and code bases, leading to single-vendor network deployments. This makes it difficult for new entrants to bring disruptive solutions to market.

O-RAN disaggregates the base station design and standardizes interfaces between different functional components, enabling component virtualization and artificial intelligence orchestration. O-RAN has now become the official 5G strategy of the U.S. and major Western wireless vendors have embraced it as part of their future base station design. Additionally, because of O-RAN, a range of smaller manufacturers have been able to competitively enter the market, offering interoperable solutions that can help keep market pressure on pricing.

Decentralization has recently become associated with distributed ledger, blockchain technologies, as part of the broader Web3 movement.[2] However, many decentralized technologies do not rely on blockchain. In addition to O-RAN, examples broadly include things like github for open-source software and social media platforms like Mastodon.

Web3 sought to help directly monetize decentralization through cryptocurrency to create new business models for the internet. However, hyper-financialization led to the speculation bubble and rampant fraud that ultimately knocked the wind out of Web3. Here we explore the broader notion of decentralization, which may or may not be enabled by blockchain.

## Platform Approach

As the U.S. and its allies make generational investments in S&T, they collectively seek to make as much progress as possible, as efficiently as possible, but within the framework of free-market liberal democracy. Lacking instruments of authoritarian industrial policy, the U.S. and its allies need approaches to bring efficiency to diffuse national investments.

International standards are one approach, but have become increasingly politicized. Standards in areas such as telecommunications are lumbering documents designed for the pace of a hardware-driven technology economy. Something more agile is necessary.

In most every technology area, software is king. Over the past decade, software engineering has embraced agile development methodologies, and development security operations—DevSecOps—are now the law of the land. This methodology involves rapid iteration of software that conforms to a broad architecture. Agile development is now intrinsic to modern digital engineering. Rather than spending years negotiating complex standards, a federated development community contributes to common code bases in real time. Interoperability results from common architectures and interaction through published application programming interfaces.

Effectively decentralizing technology R&D requires common digital platforms on which teams of researchers across the world can collaborate. If research communities in the U.S. and its allies can agree on standardized digital platforms, the opportunity for decentralized innovation will be tremendous.

## Candidate Platforms

Here we explore potential platforms associated with specific technology areas.

### Next Generation Telecom Technologies

As wireless technology continues to evolve from 5G to 6G, industry continues to see increased *softwarization*. Core 5G standards envision a cloud-native architecture in which control plane functions are all virtualized, scalable microservices. O-RAN's push toward virtualization furthers the march to a software-heavy vision for 6G. If 6G is predominately software, then rapid innovation should be feasible through a software-based approach to development.

The Defense Advanced Research Projects Agency began to build a software platform with its companion programs: OPS-5G and OPA-5G. It partnered with the Linux Foundation to make 5G infrastructure as ubiquitous as any other open-source software service. As the *softwarization* trend continues, open source toolsets such as these could become the scaffolding for decentralized innovation from 5G into 6G. Industry organizations like the Telecom Infra Project are operationalizing similar concepts at scale.

Radio frequency spectrum is another area that could benefit from decentralization. As 6G anticipates the need for significant additional spectrum to meet network capacity demands, spectrum sharing will be a necessity. R&D on decentralized spectrum sharing could be a critical enabler and form the basis for another digital platform.

## Artificial Intelligence and Machine Learning (AI/ML)

Centralized cloud infrastructure such as Amazon Web Services and Google Cloud Platform has driven innovation in AI/ML over the past two decades, resulting in rapid advancements. However, the need for computation for training, fine-tuning, and inference is growing exponentially. AI/ML computational needs might rapidly outpace centralized cloud resources, and the costs associated with such models are expected to skyrocket.

Decentralized computing infrastructure presents an opportunity to combine edge computing resources into a decentralized cloud for AI/ML, one that will simultaneously bring additional resources to enable edge inference and training, as well as reduce the latency between the end user and the AI/ML model. Over the past decade, edge computing has allowed decentralization of cloud computing, with the ability to distribute workloads to mobile devices, edge compute nodes operated by telecom companies collocated with cellular base stations, or central cloud datacenters. Hybrid AI/ML models that can operate in data centers, on users' phones, and on the ubiquitous compute infrastructure underpinning modern telecom networks allow for everything from low-latency inference to data locality and privacy.

In addition to cloud costs, the need for federated machine learning (FedML) systems is rising as enterprises come together to work on projects. With FedML, enterprises can collaborate on AI/ML tasks without revealing their individual data sets to their competitors while still benefiting from a collaborative model. FedML systems are fundamentally decentralized and trustless in nature, and benefit from privacy guarantees while simultaneously ensuring greater efficiency and productivity for each participating enterprise.

## Semiconductors

Semiconductor manufacturing has traditionally been monolithic and centralized, requiring massive investments for each fabrication and each integrated circuit (IC) manufactured this way. The rise of fabless semiconductor companies has partially, but not entirely, decoupled design from fabrication.

Chiplets, with modular ICs and hybrid integration, enable a new paradigm of System on Chip (SOC) manufacturing in which multiple disparate vendors working on specific classes of semiconductor manufacturing can collaboratively produce a highly sophisticated SOC. This means breaking SOCs into chiplets and integrating them enables more scalable semiconductor manufacturing that is more resilient to supply chain challenges, requires lower amounts of investment per facility, and ensures long-term competitiveness and sustainability in semiconductor manufacturing within the U.S.

Additionally, the semiconductor industry can further decouple design from fabrication by adopting open platforms for electronic design automation tools, with interoperable logic cores, open cloud-based design, and synthesis engines that are less targeted to specific fabrication facilities and companies.

## Supply Chain Management and Manufacturing

Supply chain systems tend to be distributed in nature, with multiple participants providing components that are consumed, altered, or integrated into an overall manufacturing process. Even then, supply chain management systems have traditionally been centralized, with a contract management and single software system designed to manage all aspects, including bids/pricing, procurement, and provenance. Such systems are limited in their capability for manufacturers to check the provenance of supplied components, manage the procurement process in a scalable manner, and transparently handle bidding/pricing.

Using decentralized systems, multiple manufacturers can collaborate (securely and privately) to gain a deeper understanding of pricing and associated contracting of components and their provenance. An example of this is the emergence of Software Bills of Materials, which provide a manifest of software components within a software application, allowing supply chain illumination and risk analysis by software deployers.

## Biology and Chemistry

Like the AI/ML industry, computational sciences, particularly in the domains of computational biology and chemistry, have relied on centralized supercomputing resources to generate results. However, distributed computing resources can also be used for computationally challenging tasks in sciences. For example, the distributed protein-folding algorithm Fold-It uses edge computing resources to determine three dimensional structures of proteins. There is tremendous potential in leveraging edge computing resources to similarly solve difficult problems in chemistry, material science, physics, biology, and other related disciplines through parallelized algorithms for determining new molecules, structures, bonds, and reactions in computational sciences.

Physical and experimental biology and chemistry can also benefit from decentralization. The emerging concept of “cloud lab” brings virtualization to wet labs. With laboratory protocols unambiguously described as a computer program, automated laboratories can conduct biology and chemistry experiments as a service. The pharmaceutical industry is increasingly using these services for drug discovery, with AI/ML guiding the evolution of laboratory protocols. Interestingly, this approach also allows portions of complex protocols to be executed computationally, rather than physically, if results are deterministic and already known. Additionally, laboratory protocols can be automatically parallelized and executed across multiple, interoperable laboratories.

These concepts can also be applied further up the chemistry/biology stack. For example, MITRE is leading an effort to disaggregate the synthetic biology workflow into interoperable elements that can be composed into engineering solutions. MITRE is founding the BioNet Alliance, which will establish and standardize the key interfaces in these workflows, including design, DNA composition, DNA synthesis, strain construction, evaluation, and scaling. Innovation in the way synthetic biology projects are built can decentralize the bioeconomy and expand innovation.

## Virtual Reality (VR), Augmented Reality (AR), and eXtended Reality (XR)

With virtual, augmented, and mixed reality playing a greater role in society, the need is growing for communication and computing resources at the edge of telecom networks and proximate to users to render images, multimedia, and other content for VR/AR/XR and related applications. Due to latency and other constraints, there are few, if any, centralized means of performing these functions. Moreover, centralized solutions do not scale well with an increase in device density. Therefore, for immersive multimedia applications of the future, decentralized edge computing will be essential for scalable, reliable, and high performing systems.

## Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2X)

Vehicular systems have traditionally been relatively uncoupled and inherently decentralized in nature. With these systems increasingly using AI and automation, there is a growing emphasis in the automotive industry on V2V and V2X communication/networking, control, and interactive decision making. Such interactive vehicular systems typically cannot be designed to operate in a centralized manner, as the resulting centralized system does not scale well and suffers from latency and performance challenges. Decentralized edge coordination and control between vehicles is the highest-performing, efficient, and scalable solution for improved safety and increased throughput in vehicular systems.

## Robotics and Multi-Robot Systems

Like vehicular systems, robots of all categories benefit considerably from decentralized protocols for compute, storage, and interactive coordination. Both single- and multi-robot systems benefit considerably from sensor-fusion algorithms, peer-to-peer communications/networks, edge AI/ML, edge rendering/vision algorithms, and hybrid control/distributed decision making. This notion brings together many of the decentralized components discussed in previous sections. A multi-robot system is a platform of platforms, enabling decentralized operations that scale with performance guarantees, highlighting many of the benefits of distributed thinking for intelligent systems of the future.

## Decentralized Identity

Incubator grants awarded by Department of Homeland Security S&T over several years incentivized industry to advance tech stacks for decentralized identity. The aim here is to give citizens control back over their identity elements and provide true identity portability without being beholden to federated identity providers. Standards for Distributed Identifiers and Verifiable Credentials have begun to mature and have been used in digital COVID vaccination cards and as a means to register refugees for benefits and services.

# Recommendations

As the U.S. and its allies build both domestic and global S&T strategies, they should do so with an underlying commitment to decentralized approaches. These approaches are well aligned with free-market, multilateral, and anti-authoritarian values.

These strategies can be enabled by adopting a platform-based approach that provides the necessary scaffolding for decentralized innovation to hang together. These platforms should favor agile software-based frameworks over complex standards.

The following are concrete policy recommendations that can be considered to advance the notion of decentralized innovation.

**Decentralized Innovation Playbook:** The administration should commission a study with the National Academies to develop a decentralized innovation playbook that can build on the example platforms described herein, extract common themes and lessons learned, and propose a repeatable approach to decentralized innovation.

**American S&T Strategy:** The Office of Science and Technology Policy should develop a cohesive S&T strategy that includes decentralized principles in its approach. The strategy should knit together the wide range of existing domestic investments from the Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act and identify key international partners with whom the U.S. seeks to establish multilateral S&T partnerships in each critical and emerging technology area.

**Fostering International R&D Collaborations:** The National Science Foundation (NSF) should use its existing funding programs to support graduate student, postdoctoral fellow, and faculty exchanges between U.S. universities and global universities in partnered nations per the American S&T Strategy.

**Global Platforms Program:** The NSF should launch a global platforms program that co-funds multilateral programs with S&T funding agencies in partner nations, aligned with critical and emerging technology areas. These programs should include the decentralized innovation approach to the programs they fund.

**CHIPS and Science Programs:** The CHIPS and Science Act invests heavily in place-based innovation across a wide range of programs, including the Economic Development Agency's TechHubs program, the NSF Regional Innovation Engines program, the Department of Energy Innovation Hubs program, and the consortium structure of the semiconductor research investments. These programs should all adopt a decentralized innovation theme and seek to build and leverage common platforms to accelerate interoperability across different programs and hubs, while also creating stronger pathways for translational research and global collaboration.

**Embed Decentralized Innovation into New Programs:** As the administration and Capitol Hill undertake S&T legislation, such as reauthorizations of major programs like the National Quantum Initiative, or new legislation on artificial intelligence, notions of platforms for decentralized innovation should be considered and supported.

## About The Authors

**T. Charles Clancy, PhD,** is a senior vice president at MITRE where he heads MITRE Labs and is the organization's Chief Futurist. He seeks to develop a future where technology is democratic, sustainable, and equitable. He previously served as the Bradley Distinguished Professor of Cybersecurity in the Department of Electrical and Computer Engineering at Virginia Tech, where he led the Hume Center for National Security and Technology. He is a fellow of the IEEE.

**Sriram Vishwanath, PhD,** is a professor of electrical and computer engineering at the University of Texas, Austin. His research broadly includes decentralized technologies, wireless communications, and machine learning. He is a serial entrepreneur and was named the University of Texas's Entrepreneur of the Year in 2014. Sriram is a fellow of the IEEE and a senior member of the National Academy of Inventors.

## Acknowledgements

The authors would like to thank Duane Blackburn, Katie Enos, EJ Hillman, Marc Salit, and Sanith Wijesinghe for providing input and review to this document.

# Endnotes

[1] E. Raymond, *The Cathedral & The Bazaar: Musings on Linux and Open Source by an Accidental Revolutionary*. Cambridge, MA, USA: O'Reilly Media, 1999.

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