Research and Infrastructure Challenges for Applications and Services in the Year 2021

Prasad Calyam¹, Glenn Ricart²

¹University of Missouri-Columbia, ²US Ignite and University of Utah
calyamp@missouri.edu, glenn.ricart@us-ignite.org

This article is an editorial note submitted to CCR. It has NOT been peer reviewed. The authors take full responsibility for this article’s technical content. Comments can be posted through CCR Online.

ABSTRACT

The Applications and Services in the Year 2021 workshop was successfully organized on January 27-28, 2016 in Washington DC through funding support from the National Science Foundation (NSF). The goal of the workshop was to foster discussions that bring together applications researchers in multidisciplinary areas, and developers/operators of research infrastructures at both national, regional, university and city levels. Discussions were organized to identify grand challenge applications and obtain the community voice and consensus on the key issues relating to applications and services that might be delivered by advanced infrastructures in the decade beginning in 2020. The timing and organization for the workshop is significant because today’s digital infrastructure is undergoing deep technological changes and new paradigms are rapidly taking shape in both the core and edge domains that pose fundamental challenges. The key outcomes of the discussions were targeted to enhance the quality of peoples’ lives while addressing important national priorities, leveraging today’s cutting edge applications such as the Internet of Things, Big Data Analytics, Robotics, The Industrial Internet, and Immersive Virtual/Augmented Reality. This report summarizes the workshop efforts to bring together diverse groups for delivering targeted short/long talks, sharing latest advances, and identifying gaps that exist in the community for ‘research’ and ‘infrastructure’ needs that require future NSF funding.

1. INTRODUCTION

Today’s digital infrastructure is undergoing deep technological changes and new paradigms are rapidly taking shape in both the core and edge domains. These paradigms leverage the growing footprint of ultra-high-speed broadband networks, pervasive wireless, cloud computing, and software-defined infrastructure. Moreover, they are positioned to connect smart/mobile devices, as well as their data on a massive scale. These advances will enable transformative applications and services in the decade beginning in 2021 that will enhance the quality of peoples’ lives while addressing important national priorities. In addition, these new technologies may bridge and unite today’s cutting edge applications such as the Internet of Things, Big Data Analytics, Robotics, The Industrial Internet, and Immersive Virtual/Augmented Reality, yielding applications that are not obvious or even possible at this time.

The NSF-sponsored Applications and Services in the Year 2021 workshop was successfully organized on January 27-28, 2016 in Washington DC that brought together applications researchers in multidisciplinary areas, and developers/operators of research infrastructures at both national, regional, university and city levels. Discussions were organized to identify grand challenge applications and obtain the community voice and consensus on the key issues relating to applications and services that might be delivered by advanced infrastructures in the decade beginning in 2020.

The timing and organization for this workshop is significant and well summarized by the Looking Beyond the Internet Planning Group [1] Organizers – “Now is the time to make concrete plans for exploring emerging planetary-scale cloud / wireless / network systems beyond the Internet . . .”.

The following is a list of themes that were identified for setting the scope of the workshop discussions and to relay the topics of interest:

- User quality of life applications: use cases
- Next-generation applications and services
- Application run-time environments on federated and cloud resources
- Real-time data collection, analytics and sharing
- Supporting infrastructure including the roles of clouds, wireless/mobile and software-defined management technologies
- Federation of infrastructure for supporting applications and services
- Security and privacy requirements of applications and services in the decade beginning 2021

The workshop was organized as a collaborative forum for discussion. More than 90 whitepaper submissions were received, out of which 58 participants were invited to the workshop. The invitations were based on creating a reasonable mix of researchers, industry, city managers, regional networks and PhD students to have a diverse set of perspectives in the discussions. A workshop website was also created [2].

There were many interesting “Imagine a world” and “Imagine a time/place” stories provided in the whitepapers. A couple of examples are as follows:

- “We envision a time when sensor technology and smart healthcare systems are routinely used across the U.S. to capture subtle changes in health that may be early signs of illness and functional decline. Seniors are able to receive early treatment when health problems are
still small and manageable; healthcare is more effective and efficient, because health problems are caught early…” — Marjorie Skubic, University of Missouri-Columbia

- “A research team has been awarded time on an expensive instrument. With a few clicks, they establish a collaboration space containing data relevant to the specific experiment. Several members of the research team plus instrument scientists work within this space to prepare for the experiment. The sample(s) arrive… The entire process happens in an interactive fashion.” — Rajkumar Kettimuthu, Argonne National Laboratory

Other examples included references to: Smart Car, Smart City, Smart Grids, Smart Industrial Systems, Smart Flood Information Systems, Smart Disaster Management, and Smart Education Technology.

The other highlights from the accepted workshop whitepapers include:


- Smart Technologies Represented – IoT: UAVs, Wearables, Sensors, Virtual Reality, Augmented Reality, Robotics, 3D immersion, Haptics, …

- Data Intelligence Representation – Small Data, Big Data, Federated Data, Crowd-sourced Data, Multisensorial Media

- Infrastructure and Services Representation – Software-defined Infrastructure and Services, Edge/Core Cloud, Hybrid Cloud, Hierarchical Clouds, Named Data Networking, Science Gateways, Sustainable App Ecosystems, Visualization, …

- Security and Privacy

The main workshop goals were as follows:

1. Discuss several “themes” of research challenges in group discussions

2. Identify a set of “salient findings” and “recommendations” for ‘Applications and Services in the Year 2021’

3. Synthesize ‘community voice/consensus’ in a final report to the NSF

A pre-workshop reading list [3] [4], and [5] was selected by the Organizing Committee, and provided to the workshop participants. The whitepapers of invited participants were also available to all the participants on the workshop website [2].

As such the topics discussed, the findings from the workshop, and the recommendations for future NSF funding areas can be classified under “Research” needs, and “Infrastructure” needs as follows.

2. RESEARCH

2.1 Data Deluge Management

2.1.1 Challenges Discussed

The questions addressed by the workshop participants for this discussion theme included:

- What are the requirements of next-generation data analysis and visualization systems to derive intelligence from e.g., “things”, or social activity tracking of humans at a scale expected in year 2021?

- What are new challenges to be addressed (e.g., in discovery and search of data; verifying data veracity) to create actionable intelligence across multiple disciplines and user/provider communities? How can this intelligence be used beneficially to provide situational awareness or alter our environments in new ways?

2.1.2 Salient Findings

An explosion of data, especially from communicating devices, will upset architectures and demand new approaches. Data will be at the center of much that drives future research and development, and the economy. It will be the glue that unites the physical and cyber worlds, the key to understanding human environments, the intelligence behind personal cyber coaches, the comparative weight that allows us to balance privacy against security in each case, and the grounding for artificially intelligent agents acting on our behalf.

2.1.3 Recommendations

Recommendation-1: Improved data science techniques for harvesting, collecting, processing, compressing, storing, archiving, sharing, and transmitting data are needed to deal with the data ‘deluge’ we (e.g., researchers, enterprises, and cities) are increasingly experiencing. Archived information from a variety of data sources will be the basis for groundbreaking research, and hence techniques to make data more accessible and manageable are critical.

Recommendation-2: “Computing at the Network-Edge” paradigms are needed that are secure, privacy preserving, and able to support real-time analysis in multi-tier infrastructure environments, in spite of any first-mile (data collection sites) and last-mile (data consumption sites) network limitations. Research on Locavore (edge) clouds (also called Fogs and Cloudlets) is urgently needed to explore how they can best accept, learn from, and take decisions based on massive streams of local IoT data, while also sharing contextual information with other locavore clouds.

2.2 Interdisciplinary Research Collaborations

2.2.1 Challenges Discussed

The questions addressed by the workshop participants for this discussion theme included:

- What are the top 5 application paradigms that may start seeing planetary-scale growth based on history and trends in related technologies convergence or changing social behaviors in the society? You may consider paradigms such as e.g., locavore clouds, self-federating systems, personalized cybercoaching.

- What are the factors that have kept some of the application areas (e.g., virtual reality) that for a long time showed promise but have not had larger impact?
2.2.2 Salient Findings

Applications in the national priority areas (healthcare, education, public safety, citizen innovation, etc.) are good drivers for interdisciplinary research. An especially good example is disaster management because it pushes science in many areas, and requires impactful interdisciplinary collaborations. Support for science advances and innovations in national priority areas can benefit other application areas or wider technology infrastructure in rural areas or under-developed country regions, and have broad societal impact.

2.2.3 Recommendations

Recommendation-1: Interdisciplinary collaboration should be strongly encouraged because it will be a foundational aspect for addressing Global Challenges (approaching as a community rather than as separate disciplines). A “systems approach” is needed with more of an interdisciplinary team approach (machine learning+ videoanalysis+ sensors+ networking+ HPC+ SDN+ security+ datascience+ health-science+ policy+ . . .) i.e., “diversity will breed bold discovery”.

Recommendation-2: Research and development for disaster management applications and new techniques for related infrastructure setup and management should be particularly encouraged. This is because advances for this example application will have to address multi-disciplinary challenges and overcome the fact that general assumptions of infrastructure availability may not hold true for users in a disaster incident area.

2.3 Data Visualization and Insights

2.3.1 Challenges Discussed

The questions addressed by the workshop participants for this discussion theme included:

- What are the gaps in approaches to co-operatively collect (e.g., for real-time analysis or historical data analysis) or compute (e.g., cloud/fog location selection) or share pertinent data sets (small, medium and big data) within user/resource federations that can be used for automated analysis, visualization and intelligence notification? You can imagine application use cases such as video content delivery, effective disaster response or cyber attack impact mitigation.

- What futuristic analytical and statistical techniques will be needed to deal with applications and services in the year 2021? You may consider topics in fields such as machine learning, optimization, computer vision, and expert systems.

2.3.2 Salient Findings

An interesting part of the applications space is its growing need for “smart services” for continuously operating ecosystems of data, interactive analysis, artificial intelligence interpretation, and human-guided visualization and intervention. There is a need to better engage human as well as artificial intelligence to gain ‘insights’ from data that can then be used to design better applications and adapt them based on user needs.

2.3.3 Recommendations

Recommendation-1: There is an urgent need for innovation in ‘interactive’ and ‘collaborative’ visualization services to obtain relevant insights from the data. Visualization needs to leverage ultra-low-latency links where available, ad hoc visualization of massive datasets (immersive reality, head-mounted displays) and be seamlessly accessible across multiple form factors (e.g., mobile device versus immersive displays).

Recommendation-2: There is a need for research into “Insights-as-a-Service” that operates as an integrated function i.e., it jointly considers function-centric orchestration in data movement, machine learning, data sharing and computing for ‘ubiquitous analytics purposes’. Such an Insights-as-a-Service paradigm can help us handle the fact that data and processing will be increasingly distributed in nature and (sometimes) federated.

2.4 IoT Privacy and Security

2.4.1 Challenges Discussed

The questions addressed by the workshop participants for this discussion theme included:

- What are the major cyber security and privacy threats to be addressed for applications and services in year 2021? Will the concepts of security and privacy themselves change by year 2021? How will the attack surface change?

- How can we provide security and privacy across heterogeneous systems with varying levels of trust? You may consider cases where e.g., security and privacy alignment is needed across multiple organizations with their own respective resource and user policies?

2.4.2 Salient Findings

Privacy and security is ill-understood in this new world (with IoT growth) both technically and socio-technically and also socio-economically. There are many unsolved hard problems in today’s users managing privacy when they interact with web servers over the “Internet of Computers” (IoC), and thus it will be much harder in the “Internet of Things” (IoT) future for users to express their privacy wishes and understand their implications in context of ubiquitous sensors and invisible applications.

2.4.3 Recommendations

Recommendation-1: Innovative techniques and usable tools for composing privacy policies and managing privacy preferences need to be developed. In the multipoint/reuse infrastructure in 2021, user data will flow across many boundaries and merge and split and aggregate. Novel research and technology should be supported that can help users or communities to compose privacy policies that make sense in a multipoint/reuse infrastructure and also carry privacy as per user or community desire throughout the data lifecycle.

Recommendation-2: At-scale research experimentation should be encouraged with establishment of large testbeds of real users with diverse preferences in order to create a privacy-protected repository of preference data that can be used/re-used by researchers. Academic research on data privacy should recruit subjects with life experience or broader perspective to reflect the diversity and complexity of the
population at large to raise logistical and (ironically) privacy challenges that can be addressed through large-scale user/infrastructure experimentation.

3. INFRASTRUCTURE

3.1 Living Labs

3.1.1 Challenges Discussed
The questions addressed by the workshop participants for this discussion theme included:

- What are the fundamental barriers and opportunities for new experimental methodologies that will shape the infrastructure and services for applications in the year 2021? You can consider issues that will influence applications in the year 2021 in the context of: next-generation emulators/simulators, increase of complex systems that are inter-dependent, ability to re-use proven configurations for repeatable science, or new ways of human-computer interactions.

- What will be the nature of collaboration necessary between industry and academia to meet the infrastructure and service needs of applications in the year 2021? You may consider issues such as building blocks collaboratively developed within open software, open systems or other areas of open innovation.

3.1.2 Salient Findings
Cities, enterprises and university citizen communities can be leveraged as interesting initial testbeds and even ‘living labs’ to solve the application and service challenges in a IoT world of the year 2021. The IoT infrastructure supporting the applications of 2021 will create an even more complex tangle of data and computational channels—tiny devices and big-data backends—spanning jurisdictions, economies and cultures.

3.1.3 Recommendations
Recommendation-1: Students and citizens should be encouraged to “live in the future” as part of ‘living labs’, and push the limits of what we can imagine in terms of futuristic possibilities, and unexpected new frontiers for innovation. Such efforts should focus on improving the productivity as well as improving quality of human life through the use of new and advanced technologies.

Recommendation-2: Living lab testbeds can foster interdisciplinary research, marrying the IT fields of computer science and engineering with the human-oriented fields of sociology and psychology and economics. In addition, specific “grand challenges” can be pursued; one might study of culture and trust amongst users in smart city eco-systems, where research experiments enable “home testing” of security/privacy in the IoT infrastructure of 2021 (the same way users can test their tap water today). Alternately, these testbeds can help overcome any regulatory obstacles in public spaces that have been a significant barrier to deployment of IoT and cyberphysical systems (e.g., in case of UAVs or wearable computing in public spaces).

3.2 Broad Infrastructure Footprint

3.2.1 Challenges Discussed
The questions addressed by the workshop participants for this discussion theme included:

- How will the convergence of growing advances in diverse domains (e.g., hardware at both edges and core, distributed computing frameworks, web technologies, autonomous management with software-defined infrastructure) enable new application realities in the year 2021? You may consider use cases, computing paradigms or technologies that will become possible that are in early stages today but have immense promise.

- How will ‘shared edge computing’ or ‘massive-scale public clouds’ need to evolve for supporting applications and services in the year 2021? You may consider evolution issues such as bit rates/latency, compute cycle access/pricing methods, service interfaces in terms of usability, or security tools for device-to-service or device-to-device communications.

3.2.2 Salient Findings
Infrastructure that is broadly available should allow for testing of Year 2021 applications and services at scale. Driven by the data explosion as well as the consumerization of devices that brings more and more people online—not to mention devices/IoT—systems and applications need to be designed to quickly expand and scale.

3.2.3 Recommendations
Recommendation-1: There is need for federated, deeply programmable, open, sliceable and sharable infrastructure for experimentation (similar to current GENI, CloudLab, Chameleon and beyond). Locavore infrastructure is especially needed at the edge for applications with low-latency requirements. With broadly available infrastructure that can be operated as software-defined infrastructure, new solutions for national priority application areas (such as smart manufacturing systems) can be realized.

Recommendation-2: Infrastructure should be designed and deployed in simple abstractions as well as with realistic application targets and use cases. Proposed approaches for infrastructure design should have minimal specificity (end-to-end), generic, and simple enough to maximize the generality of the resulting solution across multiple disciplines and user groups.

3.3 Security Assurance

3.3.1 Challenges Discussed
The questions addressed by the workshop participants for this discussion theme included:

- What are the capabilities that need to be available to users, application developers and service providers that can improve ease and quantity/quality of “access” to infrastructure resources that are owned by multiple entities?

- What new transformative innovations and cultural changes in security and privacy are needed to deal with the coming “Internet of Things”? You may consider cases where humans cannot effectively reason about security and privacy when: devices become too long-lived, too cheap, too tightly tied to physical life in personal spaces, too invisible, and too many.
Recommendation-1: New techniques and related tools to conspire to create new security challenges. Turing methods, increased distribution and sharing—will all more widely shared. Several factors such as: scale of devices, size of data sets, economy due to cheaper manufacturing methods, increased distribution and sharing—will all conspire to create new security challenges.

Recommendation-2: Investigation of innovative methods to make it easier for researchers and programmers to build distributed systems the right way quickly from a security standpoint should be developed. The infrastructure of 2021 will require even more distributed systems that are quickly provisioned and effectively managed. Flexible and extensible web technology stack research is needed to handle the technical, policy and legal specifications relating to infrastructure resources owned by multiple entities servicing users/devices at massive scales.

3.3.3 Recommendations

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**Recommendation-2:** Investigation of innovative methods should be encouraged that allow automated security verification for human analysts and software engineers. Proposed solutions would likely need to balance the advantage of full white-box testing with the privacy of source and design internals; successful solutions here will also likely need to figure out how to significantly increase assurance that this system-of-systems is secure, while recognizing the fundamental difficulty of “100%” confidence.

4. CONCLUSION

Applications and services based on computer science research are an integral part of the national innovation and economic development ecosystem that powers the United States economy and citizen quality of life. As just one example, the Internet alone has been adding 21% to economic growth over a recent 5-year period. However, by the year 2021, the architecture for today’s web-oriented cloud-based Internet may well have reached full maturity and may no longer be contributing to growth at historical rates. Fortunately, we are now in the midst of a blossoming of new wireless and Internet technologies and growing human talent base; with proper research funding and with attention to the applications and services that research can enable, there is a real opportunity to spur a whole new decade of improvement in our economy and quality of life.

There were many interesting “imagine a future”, “imagine a time/place” stories and innovative use of advanced technologies discussed at the workshop by invited speakers and between workshop participants in discussion groups. In all these discussions, the community consensus and voice was clear—that NSF should continue to fund and consider expanding support for research that has broader impacts when applied to national interest applications and services. In formulating research programs at NSF, such broader-impact opportunities should be carefully considered. Grand challenge applications can often spur creativity and new insights for fundamental research. But, similarly, curiosity-driven research can be the catalyst for advances in economic competitiveness, healthcare, education and workforce development, energy, transportation, advanced manufacturing, and smart and connected communities.

Innovation in national interest applications and services can add value to fundamental and applied research in two very different ways: (i) they can translate the fundamental advances of curiosity-driven research into valuable advantages and benefits for Americans and the communities in which they live, and (ii) they can pose unsolved challenges that may suggest new and untraveled approaches for fundamental and applied research. Two examples can be considered in this context in terms of value creation. First is the NSF’s GENI program investment that engendered and expanded the field of software-defined networking, which in turn has led to a vibrant industry sector in Internet and Cloud technologies in which American companies excel. Second is the research spawned by the NASA Apollo program, which posed unsolved “moonshot” challenges that ultimately ended up creating new materials such as Teflon and Velcro. Both modalities will help to add bold innovation and growth to the national economy and improve the quality of life for all Americans and for citizens in the rest of the world.

5. REFERENCES