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SMARTPHONE BREAKOUT SESSION REPORT

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1 — INTRODUCTION

Phones are the first pervasive mobile computing technology. Between 1990 and 2010 the number of mobile phone subscriptions grew by two orders of magnitude. Today's phones are migrating from so-called feature phones—limited to voice and text messaging—to smartphones which integrate powerful processors, multiple communication technologies, ample storage and sensor suites. The ubiquity and increasing capabilities of smartphone devices make them our best option for realizing the pervasive computing vision at scale.

2 — CURRENT STATUS

Today's smartphone is as powerful as larger mobile devices were several years ago. It integrates multiple processors, including some specialized for specific tasks. It can communicate data over 1,000s of meters to cellular towers using 3G or 4G, over 10s of meters to 802.11 access points using Wi-Fi, and over 1s of meters to many other devices using Bluetooth. This array of communication technologies mean that phones may provide last-hop communication to body area and other deployed sensors that lack the power required for long-distance communication. Cheap and plentiful storage allows smartphones to cache a great deal of information, and the growing power of the cloud allows them to offload expensive computation. The emergence of application distribution channels like the Apple AppStore and Google Android Market have accelerated smartphone innovation by providing access to millions of deployed iPhone and Android devices.

3 — VISION AND CHALLENGES

To frame our discussion of the future of smartphone research, our session outlined a vision of the smartphone in 2020. We imagine the capabilities of Phone 2020 and some exciting future applications below. Working backward, we develop a set of research challenges that must be addressed before Phone 2020 can become reality.

3.1 — Phone 2020: The Next Decade of the Smartphone

In a distracted world, Phone 2020 will help us deal with the data deluge by offloading much of the current human burden caused by information overload. Phone 2020 is itself continuously capturing large quantities of data about our lives—including location traces, readings from internal and external sensors, and logs of our mobile-based activities—and contributing to the steady increase in data collection. But it will also help analyze and interpret these new data streams to maximize their value. By learning our patterns, Phone 2020 will make suggestions about our daily lives, anticipate our actions, and become woven into the fabric of our existence.

In order to assist us, the future smartphone will interact with everything—other phones, the cloud, nearby sensors and actuators, vehicles and buildings—and display information in ways tailored to each user. It will process the environment and help us discover and navigate the world around us, including visibility into social networks. By better understanding users, the Phone 2020 will manage their attention and know when to interrupt. Through an increase in its own capabilities and by seamlessly inter-operating with powerful cloud resources, Phone 2020 will be starting to make desktop and laptop computers obsolete.

The new capabilities of Phone 2020 will support new applications that open up new markets. Smartphones will define the classroom of the future. They will augment reality to further education, socialization, health care and gaming. They will sense reality to manage cities, workplaces and traffic while continuously recording our digital lives. Smartphones of the future will help us work more efficiently, serving as portable office and personal digital assistant, conserving useful working hours and creating time for leisure and entertainment. We expect future applications to be long-lived—leveraging continued interaction with users over time—and local—exploiting the density of smartphone penetration to augment or replace communications infrastructure, critical in developing countries where such infrastructure may be unreliable or nonexistent. The ubiquity of smartphones and their proximity to their human users will make them a critical component of future approaches to disaster relief and emergency management.

Phones will also continue to be integrated with online social networks. Smartphones are already the quintessential social device. The desire of people to connect with each other drove the adoption of cellular phone technologies. With social networking exploding on the Internet in 2011, Phone 2020 unites the social network with the social device. It will help us further understand the structure of existing social structures, while assisting in the formation of ad-hoc social networks grounded in physical gatherings of people with similar interests. Phone 2020 will also contribute to network science by monitoring user behavior and supporting applications such as disease tracking.

3.2 — Challenges

In order to build Phone 2020, we identified a number of challenges that our community must address. These divide into three categories: (1) developing the capabilities of the smartphone and its environment, (2) improving interaction between smartphones and users, and (3) coping with the potential for massive large-scale data collection using smartphone-integrated sensors.

The Phone 2020 vision is predicated on continued improvements to smartphone and smartphone infrastructure performance. Future smartphones must be more powerful, communicate more quickly, store more data, and integrate new interaction technologies. Unfortunately, these goals are at odds with data bandwidth and battery capacities, both of which are scaling slowly. We expect future smartphones to deploy opportunistic algorithms that multiplex both time and space in order to improve performance. The overall heterogeneity of deployed devices and standards is another challenge limiting device-to-device inter-operation and the potential for Phone 2020 to interact with all the devices it encounters. We also discussed the importance of integrating the smartphone with existing Wi-Fi networks to improve connectivity and network performance. Peer-to-peer architectures were suggested as a potential way to improve performance, particularly when infrastructure is lacking.

Another property that is not scaling is human attention. We already pay too much attention to our smartphones to believe that we have achieved the invisibility captured by early visions of ubiquitous computing, and this problem is worsening. To better optimize our attention future smartphones must deploy interfaces allowing more nuanced interaction with users and capable of processing emotional cues. To improve the interaction between humans and their devices, new algorithms must be developed enabling behavior-based modeling, computing, and testing. In addition, user interfaces need to be reconsidered, including those that, while unsuitable for larger devices, may work well on smartphones. Phone 2020, with its ability to interact seamlessly with objects around it, will be able to leverage "found" interface elements in the environment to enable much richer interaction modalities than those possible on the smartphone itself.

Smartphones hold the potential both to contribute to and to alleviate the growing data deluge. Large-scale deployment of sensor suites on smartphones combined with cheap bandwidth and storage will lead to a growing amount of data produced by the smartphones of the future. Securing this information—much of it sensitive and personal—will be a major challenge. Designed as a personal device, smartphones are increasingly interacting with each other and the environment, creating new opportunities to steal and misuse information. Developing security and privacy models that users can understand and adapt to their needs is a critical challenge to the continued advance of this technology.

Interpreting and processing the collected data will also be difficult. There are opportunities for harnessing the distributed power of large numbers of smartphones through collaborative computation. These capabilities, if developed, might complement the continued aggregation of computation in the cloud. Fundamentally, however, the smartphone of the future will be a portal to the intelligent processing and management of data in order to reduce user distraction and allow users to focus their attention elsewhere.

4 — Recommendations to NSF

Our recommendations highlight areas where the research community can make significant and distinct contributions. Industry is already very active in this space and has many advantages, particularly when working at scale. However, there remain many opportunities for the academic community to develop the future smartphone in directions complementary to those being pursued by industry.

4.1 — Research Support

We recommend that the NSF develop research programs addressing the key challenges to realizing the Phone 2020 vision outlined above:

1. We need to continue the development of smartphone and infrastructure capabilities to support demanding new applications.
2. We must tear down the walls that divide devices from each other and limit the ability of the smartphone to fully understand its environment.
3. We need better interfaces allowing the future smartphone to conserve human attention.
4. We need smartphones to help users cope with the ever increasing amount of data accessible to and collected about them.
5. We need security and privacy models that users can understand and adapt to match their expectations and the current context—the highly dynamic pool of surrounding devices and communications channels, the social setting, and the users activity.

6. We believe it is important to understand and document our continued co-evolution with our mobile devices: how we are changing them, how they are changing us.

4.2 — Infrastructure Support

To enable academics to succeed at complementing industry, the NSF should provide them with resources and infrastructure facilitating experimentation at scale. NSF can also take a role in partnering with industry to gain access to large numbers of smartphones, air time, call logs or other large data sets. Further partnerships with industry might also allow us to do citizen-driven science in other areas that leverage the smartphone as a pervasive computing platform.

Application distribution channels like the Android Market and Google AppStore also provide academics with the opportunity to deploy research systems at scale by leveraging channels established by industry. We can release our own code on the AppStore, perhaps piggybacking on top of other popular applications. Users worldwide might be willing to participate in a large-scale virtual laboratory. At sufficient scale such a laboratory could provide built-in guarantees to researchers allowing academic research to reach large numbers of deployed smartphones.

4.3 — Educational Opportunities

One germane direction for the academic community to explore is in the use of smartphones to enhance education and learning. The future smartphone may enter the classroom and help put lessons in context, as well as extending the reach of learning beyond the classroom.

We also believe that continued growth and competitiveness in the smartphone market depends on educating the next generation of computer scientists on smartphone development. Given the centrality of the smartphone and the cloud to future computing, we must train engineers that can help integrate these two technologies in ways that harness the properties and capabilities of both. We recommend support for the continued development of courses in smartphone programming, application development, and smartphone-cloud interaction.