WOMEN IN NETWORKS: PROFESSOR CECILIA MASCOLO

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Cecilia Mascolo is Professor of Mobile Systems in the Department of Computer Science and Technology, University of Cambridge, United Kingdom. She is a Director of the Centre for Mobile, Wearable System and Augmented Intelligence and a Fellow of Jesus College Cambridge.

Her research interests are in mobile systems and data for health, human mobility modeling, sensor systems and networking, and mobile data analysis. She has published in a number of top tier conferences and journals in the area and her investigator experience spans projects funded by Research Councils and industry. She has received numerous best paper awards and in 2016 was listed in "10 Women in Networking/Communications You Should Know." She has served as an Organizing and Program Committee member of mobile, sensor systems, networking, and data science conferences and workshops. She is currently on the Steering Committees of ACM MobiSys and ACM Ubicomp. She has delivered a number of keynote talks at conferences and workshops in the areas of mobility, data science, and pervasive computing and systems. She kickstarted the ACM Sigmobile Highlights program, which selects papers from ACM Sigmobile conferences to be pushed in the ACM Communications Highlights Section as well as published in *ACM GetMobile*. She received multiple awards including the ACM Ubicomp Test of Time Award for her work on EmotionSense (published in *Ubicomp 2010*) as well as various best and distinguished paper awards at ACM Ubicomp, ACM IMWUT, and IEEE Percom. She also received two Google Faculty Awards, an EPSRC Fellowship, and an ERC Advanced Research Grant.

She received her Ph.D. from the University of Bologna in 2001. She then started her academic career as an assistant professor at University College London where she stayed until she moved to the University of Cambridge in 2008.

In high school, in addition to Italian, Latin, and Mathematics, she was taught some basic computer science; however, the discipline in high school was very new, and teachers had just started training. As a consequence Cecilia was not taught the value of parameter passing and only discovered it after receiving a low mark in her first assignment at university when her program with one page of global variables was not well received by the lecturer.

After high school, Cecilia was undecided whether to study zoology, Oriental languages, modern Italian, or computer science. The choice was made serendipitously: computer science (as a new subject) was the only subject to have an entry exam: Cecilia liked the idea of a challenge and sat the entry exam, which she passed. She thought this was meant to be and enrolled. After her Master's dissertation, which introduced her to research (on formal specification languages and semantics), she decided she liked research and enrolled in the Ph.D. program at the same university, winning a bursary. During her Ph.D. she spent one year as a visiting student at Washington University in St Louis and one at University College London. She enjoyed the research environment in both places and decided to remain abroad. She was lucky to be accepted as lecturer (assistant professor) in the Department of Computer Science, University College London soon after her Ph.D. award.

Her interest in mobile systems grew and shifted through the years from their formalization and semantics to more practical and systems problems. Her publication domains ranged as a consequence from more software engineering conferences such as ICSE and FSE to conferences pertaining more to systems domains such as SenSys, Mobicom, MobiSys, and Ubicomp.

Since their invention, smartphones (and more recently other wearables such as smart watches) have attracted the interest of researchers of various disciplines. These devices are seen as the first computational platform following the user in their daily activities. The presence of sensors and a variety of radios in these platforms presented the opportunity of potentially "measuring" behavior at unprecedented scale and with unprecedented granularity. However, such innovation introduced numerous challenges, namely:

- Is the accuracy of sensors sufficient to measure behavior? At what precision and what behavior?
- To what extent are measurements possible and at what granularity given the energy constraints of the devices? Can this be improved with system advancements?
- Which machine learning techniques could be devised or used over data generated in this manner, which has sparsity issues and time dependencies, and often, contains complex network structures, imposed by its (human) users?

Cecilia's research over the years has concentrated on solving these questions, which, in turn, have enabled mobile and wearable systems to become usable tools in other disciplines, ranging from medicine to psychology and from architecture to zoology.

Mascolo initially studied the problem of decentralized data sharing and communication in mobile devices. She researched specific primitives for communication that allowed devices to store information while moving to find the best opportunities of sending data to receivers (without the need for decentralized infrastructure). Applications of this kind of research ranged from developing region connectivity to space communication in general. Previous work in decentralized ad hoc communication assumed that a connected path between nodes existed at all times, while delay-tolerant networking approaches broke this assumption, allowing for in-network storage steps and therefore more applicable solutions. The unique contribution of Mascolo was mechanisms for packet forwarding, which relied on context and mobility characteristics *unique to social beings. She exploited social theory in pioneering work*, which allowed the forwarding to happen considering the specific features of the nodes clustering tendencies over time (i.e., specific to human patterns of encounters) [1]. The embedding of social theory concepts in computational algorithms was very much unheard of around the time these protocols were developed. More concrete applications of these ideas were implemented in the framework developed to aid zoologists to monitor badgers through tags on their collars [2].

Along the same lines and considering that human behavior underpins mobility and device usage, her group devised the first social theory founded mobility model [3], which became one of the state-of-the-art models to test such protocols. The existing literature for evaluating such protocols was, at the time, almost exclusively relying on random mobility models.

Vital to the ability to use these devices to measure behavior is the ability to do so efficiently and effectively. Mascolo's group devised one of the first techniques for adaptive sensor duty cycling on mobile devices [4], allowing the device system to be reactive to the amount of sensing needed given the user context and behavior and therefore better optimizing the trade-offs between sensing and activity inference as well as energy. She also studied the trade-offs of the offloading of computation from the device to the cloud (best paper at IEEE Percom 2013 [5]) *advocating that the use of local resources can sometimes be*

beneficial while dynamic cloud offloading (sensitive to bandwidth availability and context) could offer interesting energy trade-offs. Mascolo's recent work [6] explores similar concepts for sensing activity in wearables for the ear through in-ear microphones.

More recently, Mascolo has pioneered the use of local resources on commodity wearable devices (e.g., DSPs and GPUs) for the optimization of computation on-device [7]. In particular, her papers show that for continuous audio sensing, which is generally unachievable on a commodity device without greatly impacting power consumption, the optimized use of local resources such as DSP would greatly improve efficiency and make this task, so important for many applications, much more efficient. The work advocates that local resources have been largely ignored and typically dedicated to specific tasks only. Smart schedulers able to dynamically consider them and adapt computational load across application and sensing workload and hardware resources were proposed in her work. In [7], a surprising result is described which shows that although the GPU is an expensive computational unit, if used wisely with clever purpose-built optimization for audio data, its use can become more efficient than cloud offloading even when the bandwidth is plentiful, improving both potential user privacy as well as application responsiveness. *These works have set the scene for follow-up work on the clever use of local resources and on-device machine learning model compression and analytics, which have dominated the research landscape for embedded systems in recent days.* This work led to a Google Faculty Award on Efficient On-Device Incremental Learning for Resource-Constrained Devices in 2019.

In recent years, Mascolo has been working on the use of mobile and wearable audio signals for well being and, more specifically, health diagnostics. In 2010, Mascolo's group pioneered the use of mobile phones (at the time, Nokia Symbian phones) for detection of emotions from voice (through the microphone) with on-device inference (Emotion Sense[8]). The paper won the 10-year Impact Award at ACM Ubicomp 2021 and was very much ahead of its time. It constituted the foundation of further work on audio sensing of voice and sound inference on devices. The work used Gaussian mixture models to map user voices to voices of actors acting with different emotions. The paper demonstrated the feasibility of this technique and its efficiency on-device for the first time. It was also a demonstration of the power of these devices to aid psychology to step out of the lab. Her work on audio and systems has led to her being awarded an ERC Advanced Grant on Audio-Based Mobile Health Diagnostics. The initial work done on respiratory signals and mobile devices resulted in the largest crowdsourced data collection of COVID-19 sounds through mobile phones: to date the study has collected more than 10,000 user signals of coughs, breathing, and voice. A preliminary analysis of the sounds have yielded promising results for one-off diagnostics as well as progression monitoring [9, 10].

In addition to research, Cecilia is a mother of a teenage daughter and a 14-year-old black and white cat, a keen runner, an avid crime fiction reader, and a cook of some sort. In retrospect, finding time for these research unrelated aspects of her life has made her research better.

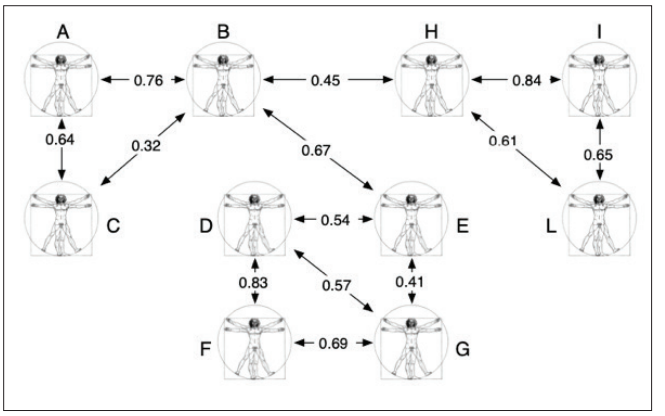

FIGURE 1. Encountering probability network for DTN routing [3].

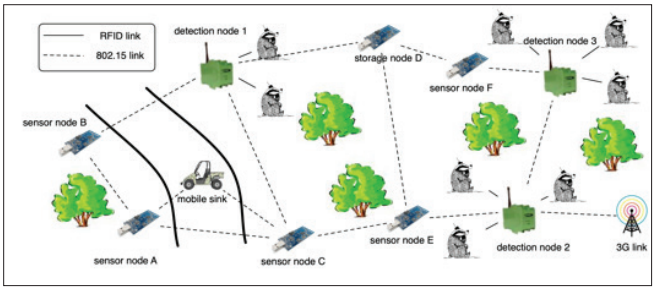

FIGURE 2. Badgers tracking deployment setup [2].

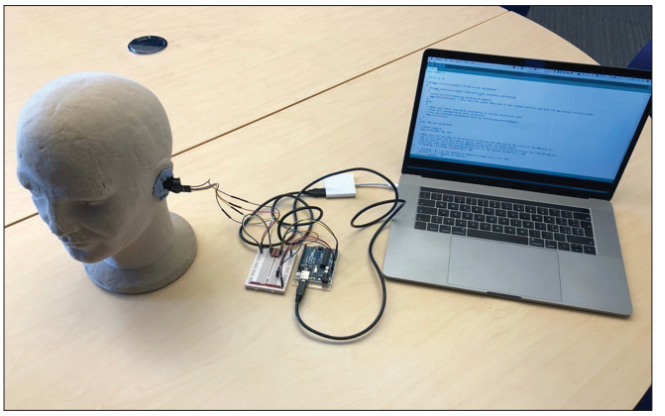

FIGURE 3. Testing wearables for ears [6].

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