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Urban Physics

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CUSP's Urban Observatory view of the east side of lower and midtown Manhattan from a rooftop in downtown Brooklyn. The night scene consists of major and minor building lights, street and river lights, and roughly 10,000 window lights. An 8 megapixel visible camera acquires three-color visible images every 10 seconds. Privacy protections include a resolution no finer than a few pixels/window.

While physics is a science, it is also a set of tools and a state of mind. Physicists have repeatedly found intellectual and practical benefit in applying their methods to new subjects; astronomy, biology, and earth sciences are prominent examples. The study of cities is another such subject now ripe to be taken up by physicists.

Understanding cities is a pressing global problem. Currently about 80% of the US and about 50% of the world population reside in urban areas, growing at over one million people per week. A city is a complex mix of infrastructure, environment, and people that must provide safety, health, housing, mobility, water, food, energy, interactions, and more recently, connectivity for its citizens. We must build new cities wisely and refurbish existing cities while improving efficiency, quality of life, and resilience.

Physicists Luis Bettencourt, Geoffrey West, and co-workers have recently offered phenomenological explanations of several macroscopic aspects of cities through theories based on scaling and network ideas from biology [1]. But what makes the science of cities even more worthy of physicists' attention now is a growing tsunami of urban data. Much as the data revolution has transformed our understanding of the physical world (e.g., the Large Hadron Collider, the Sloan Digital Sky Survey), the rapid proliferation of all manner of sensors throughout society, the digitization of commercial and governmental records, and advances in computing power and computational techniques can be combined to create unprecedented insights into urban structure and dynamics.

Granular real-time data can now show how city systems operate individually and how they interact, both with each other and with people. Sensors can report real-time traffic conditions, utility supply and consumption, bus, subway, and taxi activity, environmental quality, and crime. Social media, such as Facebook, Twitter, and Foursquare, and mobile devices that record exercise regimes and physiological parameters provide new data streams on what people are doing, how they are feeling, and what they are observing. In aggregate, these data streams are signatures of the functioning of the city and the quality of life of its inhabitants. Applying the same concepts of scientific inquiry that physicists use on a daily basis can yield new insights into how those cities work and how they can be better.

NYU's Center for Urban Science and Progress (CUSP) [2] was created in April 2012 to realize the potential of urban science. Now almost two years later, CUSP is developing into a unique interdisciplinary institution with research, educational, and entrepreneurial components designed to study and interact with New York City (NYC). CUSP aims to accelerate the definition, development, and application of the emerging field of Urban Science and Informatics.

Stakeholders

CUSP's diversity of stakeholders reflects the many segments of society that come together in cities. As a mission-driven academic institution, university partners are central to CUSP's culture and identity–advancing the frontiers of urban science and educating the next generation of researchers and practitioners is at the core of the mission. Private sector participation is essential if CUSP insights and innovations are to have impact at scale–researchers from corporate partners facilitate both technology transfer and scaling of CUSP's work. CUSP's national lab partners find an opportune venue in which to develop and exercise their sensing, data management, and modeling capabilities. But the most important stakeholder is the NYC government–CUSP's close partnerships with city agencies allow access to data, guidance in problem definition, and opportunities to demonstrate solutions.

Urban data has private sector, academic, civil society, and public sector uses. Examples include:

- Optimizing systems in real time (traffic and transit flows, gas/water/electrical grid, services delivery such as EMS, …).
- Improved infrastructure planning (land use, public transit routes, roads, utility systems)
- Monitoring the condition of infrastructure (e.g., joint corrosion in bridges, potholes, pipe leaks and blockages, insulation in buildings)
- Preparing for and managing abnormal conditions (hazard detection, emergency preparations, and emergency response)
- Increasing transparency and equity in the distribution of city services.
- Enhanced monitoring of public health (spread of infectious diseases, behavioral and environmental impacts)

In many of these examples, benefits are amplified by an open data architecture that promotes an increased understanding of the urban system in all sectors of society.

Research and Education

Four CUSP facilities are being created to anchor its research projects. First, the Data Warehouse curates and controls NYC-relevant datasets from diverse sources, including open city data, proprietary commercial data, and data generated by CUSP itself. The notions of data curation and data "users" are familiar to the high-energy physics and astronomy communities. Curating open data, which come from disparate city agencies in a wide range of formats, is a useful and important task. The Data Warehouse balances desires for openness against the proprietary and privacy concerns of the data sources.

Unlike physics datasets, much urban data is about people, entailing the need to ensure the individual privacy of the citizens whose collective behavior is being studied. Both the government and the private sector routinely collect diverse personal information. Privacy is therefore of utmost importance for CUSP's work, reflected in the responsibilities of its Chief Data Officer and the approval of the NYU Institutional Review Board for projects that involve more than open data. Other privacy safeguards include strict data access rules, immediate data encryption, and degrading of information. CUSP and its partners aspire to develop and demonstrate best practice in the responsible and transparent use of personal data in research and for public good, not only through norms and procedures but also through implementation of new technologies.

The second facility is the CUSP Urban Observatory (UO), created to observe significant regions of the city at multiple wavelengths. Multiple urban vantage points (e.g., tall buildings) afford platforms from which sensors can persistently and synoptically cover the city without the mass, volume, power, or data rate constraints inherent in aircraft or satellite observations. The range of current or future instrumentation includes multiband visible imaging, broadband IR imaging (SWIR, MWIR, and thermal), hyperspectral imaging (to measure trace gases, building surfaces), LIDAR (to study building and bridge motions as well as pollution), and radar (building and street vibrations, building motion, traffic). Important correlative data includes meteorology, topography and geolocation of scene elements; parcel and land use data, demographics, etc.

The UO has begun optical imagery of NYC, providing an excellent example of how physics finds application in CUSP. Processing nighttime images (see Figure) with well-known astronomical analysis techniques such as image registration, source identification (think of the individual windows as variable stars), color analysis, time series analysis and statistical procedures, is yielding aggregate patterns of temporal variation. Those patterns–and their variations with weather, day-of-week/ month/ season, and special events (holidays, daylight savings, elections, etc.)–are directly relevant to questions such as sleep/wake patterns, proxy measures of energy consumption, and correlation with aggregate demographic data.

The third CUSP facility is the Quantified Community. Here, some 10,000 people would live in a fully-instrumented new residential/commercial development. Simultaneous monitoring of the infrastructure, the environment, and behaviors will afford a "living laboratory" to study a slice of the city and allow controlled assessment of technology or policy interventions. What will be measured, how it will be measured, what will be learned, and privacy protections are all questions under consideration in the current definition phase of the project.

The fourth CUSP facility will be an integrated simulation of the city. Reduced models might provide insights into urban dynamics, but they must be complemented with integrated, high-resolution, validated, high fidelity models of urban systems. An integrated city model would combine traffic and land use codes with communications, economics, energy, etc., likely in an agent-based formulation. None of this is straightforward and the challenges include incorporating city "boundary conditions," determining realistic decision rules, developing methods to verify and validate complex models involving human behavior, and exploring the limits of predictability.

Urban science offers robust opportunities to use the evolving tools of citizen science. CUSP is beginning to work with citizens of New York–volunteers who acquire data using personal, mobile environmental, or stationary home sensors and who analyze data by donating computational cycles, their personal expertise, and creating apps for data visualization and analysis.

CUSP grants MS degrees in Urban Informatics, and a PhD degree is under development. The current class has 24 students, and the number is expected to rapidly increase. CUSP's educational program is defined by its strong applied component in which its students and researchers work with NYC agencies on specific problems. Examples include:

- The quantification/characterization of noise throughout the city on a 24/7 basis via in situ measurements, complaint calls, and other correlative data.
- The analysis of taxi data (pick-up/drop-off locations, time, fare, tip are available for each of the 180 million trips that occur each year) to understand mobility and economic behavior.
- The study of building energy efficiency using a combination of self-reporting, synoptic sensing, and comparative analysis using correlative data.
- The development of novel public health monitoring methods such as the genomic profile of sewage.
- The in situ monitoring and study of environmental particulates and their sources, e.g., trucks, buses, etc.

Conclusion

In many ways, CUSP resembles a "national laboratory for cities", with a strong applied research component coupled to New York City. Its researchers and students work with the city on real problems, where success is measured "on the street" or in fiscal/operational terms. CUSP physicists must work with data and computational scientists, electrical and civil engineers, social scientists, and city operators. The difficulty of understanding how complex systems work, which appeals to many physicists, coupled with an opportunity to have a positive impact on society, brought us to urban science. To successfully contribute to this new field, physicists will have to understand the accomplishments, questions, and challenges of urban research in the social sciences, a task facilitated by CUSP's interdisciplinary structure.

Physicists are trained to solve complicated problems, to handle large data sets, to develop new instrumentation, to work with interdisciplinary teams, and to apply careful experimental and modeling procedures to avoid self-deception. They have a tradition of organizing large groups of scientists focused on specific research questions. It is precisely those qualities that will enable physicists to make important contributions to 21st century urban science.

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1. L. Bettencourt, et al., PNAS 104, 7301 (2007), doi:10.1073/pnas.0610172104; L. Bettencourt, *Science* 340, 1438 (2013) doi:10.1126/science.1235823
2. See http://cusp.nyu.edu