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IMAGINING THE COGNITIVE CITY

After a fire broke out in a building visible from Yankee Stadium during the 1977 World Series, broadcaster Howard Cosell captured the zeitgeist of that moment in New York City's history with the on-air comment, "Ladies and gentlemen, the Bronx is burning."[1] New York had fallen into a decline from which many people worried it would never recover. The city was near bankruptcy. Corporations had fled to the suburbs. Crime was rampant. A couple of years earlier, a sanitation workers' strike had left fetid mounds of garbage bags piled on the streets. It was a city where nothing seemed to work anymore. Indeed, New York had become emblematic of the fate of cities across the globe. In developed economies, people fled to the suburbs to escape crime, crowding, crumbling infrastructure, pollution, and failing schools.

Today, in major world economies, young people, professionals, and empty nesters are migrating back into cities in search of economic opportunities, cultural enrichment, and fun. Meanwhile, in the emerging world, cities are magnets for people from the countryside who dream of brighter futures for themselves and their children. Estimating that one million people move into cities each week, experts predict the global urban population to double by 2050 to 6.4 billion, which would make 70 percent of the total world population.[2] Yet, at the same time, many of the problems that sent people fleeing from cities decades ago remain, stubbornly resisting traditional fixes. It's clear now that the future of cities is the future of the planet, so it's essential that solutions to those problems be found.

Fortunately, cities are tremendous engines of innovation. The urban center is where the dreamers, planners, engineers, builders, social activists, and artists congregate. The more diverse groups of people interact with one another, the more likely it is that new ideas will germinate and take root. This charged mixture, along with bold leadership and new technology, could lead to a global renaissance for cities, which could grow not just bigger but better. According to Geoffrey West of the Santa Fe Institute, cities are the sources of our problems but also can be the sources of our solutions. In order to achieve that goal, however, "we desperately need a serious scientific theory of cities," Geoffrey said at a Ted Talk in Edinburgh, Scotland, in 2011.[3] What would a scientific theory of cities look like? IBMers who study cities describe it as a large set of structures, patterns, and processes that provide a formal, quantitative approach to understanding the complex systems of cities of all sizes. In this way, people who are involved in running, planning, and building cities will be able to comprehend how the human and built systems interplay with one another. Today, different role-players in cities see the urban environment though their own lenses—the planner, the architect, the builder, the mayor, the transit boss, the financier, the retailer, the restaurateur, and the labor leader. They're like medical specialists who have tremendously deep knowledge of one aspect of human biology but don't really understand how the biological systems of the body interact. A science of cities will provide that fundamental understanding of the urban organism, a common language for discussing it, and methods for diagnosing the problems of cities.

In the new era of computing, we believe that technology will help people not only create a scientific theory of cities but act on it. City leaders and residents alike will be able to harness technologies to better understand how their cities work—and why they don't work better. And they'll be able to use that knowledge to make cities more convenient, safer, and more economically vibrant.

These days, advanced data-analytics technologies are used in cities for everything from developing crime-fighting strategies to improving the efficiency of transit systems. In fact, technology has played a significant role in the turnaround of New York City. In the early 1990s, the police commissioner, William Bratton, initiated the Comstat program, a detailed tracking of all crimes in the city coupled with weekly police department meetings in local precincts aimed at using the data to come up with improved policing tactics. Since those early days, New York's policing strategies and crime-tracking technologies have become even more sophisticated, and the crime rate has been dropping for twenty years. The latest advance in technology for policing is a network of 3,000 cameras and hundreds of radiation detectors deployed in Manhattan that look for packages that might contain bombs. The system uses artificial intelligence to review an immense amount of video imagery and radiation data in real time so a suspicious package can be spotted and checked out quickly by police.[4]

But smart policing is just one narrow slice of the vital role that cognitive systems could play in the lives of cities. City leaders and sociologists often talk about the importance of a holistic approach to solving a city's problems. Cognitive systems that learn, mine insights from mountains of data, and penetrate complexity enable this holistic approach toward the major issues cities face, from crime to traffic to pollution to education. For example, the manager of a city hospital who has identified juvenile obesity and diabetes as growing health problems in the urban communities could use cognitive computing to model a solution. This would require gathering data on all the factors that affect local children, from their home activities to the availability of healthy food in local markets restaurants, their transportation options, the proximity of safe places to play, and the culture of their families. The complexity of these data require a cognitive system that can refine and correlate the various inputs and allow the hospital team to run simulations and develop a model. This model points toward programs the hospital can initiate or advocate to improve community health.[5]

Cognitive systems have the potential to knit together all the systems in a city so they can be understood and managed better. Over time, waves of technological innovation have brought us the utilities that enable the modern city—water and sewer systems, electric grids, roads, bridges, subways, communications infrastructure. In addition, a multitude of city services emerged to provide for the health, education, safety, and welfare of residents. The computer era enabled us to monitor and control some of these systems as discrete entities. Now it's clear that none of these can be viewed in isolation. Indeed, cities must be seen as complexes of interrelated systems. We need a new utility: a cognitive fabric overlaying all the other systems that can make sense of them and manage them.

In chapter 3, we briefly mentioned a major project undertaken by the city of Rio de Janeiro, Brazil. The city has set up a state-of-the-art operations center, Centro de Operacoes Rio, where the staff monitors dozens of data feeds for information concerning weather, traffic, and medical services and anticipate looming problems, putting defenses in place to diminish their impact. Rio's operations center embodies the principle that only by considering the human-made and natural systems of a city in a holistic way can municipal leaders hope to manage the complexities of a modern metropolis.

The tropical climate that makes Rio so attractive also means that it suffers from severe storms, which endanger lives and property. The city leaders got a shocking wakeup call on April 5, 2010, when torrential rains caused floods and landslides that brought much of the city to a standstill and killed more than seventy residents. Rio's mayor, Eduardo

Paes, vowed that such a disaster would not happen again. He moved decisively to bolster defenses against weather-related disruptions with the new operations center. But the facility does much more than respond to emergencies. By coordinating the activities of more than thirty city and state departments plus private utility and transportation companies, the operations center is the first such facility in the world that is on the path to integrating all of the functions of a city in a single digital command-and-control system. Because data from all of the agencies and companies are integrated, operations managers get a full picture of what's happening in the city at any time. They can prepare for a large concert or sporting event in the same way they handle emergencies. The agencies don't just share data; representatives from the various departments actually sit side by side in the operations center and look at live videos of city streets and facilities or graphical representations of data feeds, making group decisions on the fly.

The Netherlands is also moving boldly into the realm of intelligent operations. With 20 percent of its land below sea level, the country depends on a vast network of dykes and sluices to hold back and divert sea, river, and rain water. Yet global warming and the threat of rising sea levels and droughts means the Dutch can never be complacent. So the government is launching an innovative collaboration aimed at harnessing big data to improve management of the water system while restraining costs.

IBM scientists believe that sophisticated learning systems will be useful in situations like those faced by the

Dutch. Authorities there still monitor the structural integrity of the country's dykes primarily through visual inspection every five years. But already they are experimenting with continuous monitoring using satellites and sensors embedded in the dykes. Cognitive systems will tap all of those data, learn how dykes react under normal conditions, and automatically spot anomalies that might signal breaches or the need for maintenance.

The Digital Delta initiative brings together the Dutch Ministry of Water, the Delfland local water authority, the Deltares science institute, the University of Delft, IBM, and other organizations. IBM's role is to research how to integrate and make available water-related data from more than one hundred sources to scientists and businesses so they can draw insights from them. The expectation is that when people have easy access to relevant data and tools for analyzing them, they will be able to reduce the time it takes to develop new science and technology solutions and reduce development costs.

This project could serve as a model for countries, regions, and cities worldwide that face complex challenges from climate change, natural disasters, rapid urbanization, and other large-scale problems. The Dutch government didn't try to solve this problem by itself. Instead, it formed a public-private partnership drawing on the expertise and resources of government, local water authorities, universities, and private industry. The project could teach leaders elsewhere around the globe valuable lessons about how to cope with rising waters.

AN OPERATING SYSTEM FOR THE CITY

You can think of the software undergirding Rio's operations center and the Digital Delta project as the *operating system* for the city or country, just as Linux, Windows, iOS, and Android are operating systems for computers and smartphones. Operating systems not only make command-and-control connections among all of the functions of the machines but also create a platform that enables a tremendous amount of innovation. Makers of computer hardware such as printers and publishers of software applications such as word processors essentially plug their products into the computer via the operating system. Also, since so much basic functionality is packed into the operating system, that frees other developers to focus on making useful or fun products that fit on top.

The same will go for cities. They need operating systems that make it easier to share information and coordinate functions. They also need operating systems to serve as platforms for innovation, enabling city employees, businesses, and citizens to comprehend more deeply the workings of the city and to think up ideas that make cities better places in which to live. IBM and other companies are designing and building these urban operating systems.

In the meantime, another type of urban technology is already flourishing: applications that make cities work better or help people manage their lives in urban settings. Think of them as city apps. Open-data initiatives and contests launched by cities are giving rise to an explosion of creativity—thousands of homemade, easy-to-use apps that do everything from gathering public opinion on hot-button issues to helping people plan the best way to use public transit. Some of these city apps are quite sophisticated. Streetline, a company based in San Francisco, offers a parking-space locator service in a number of cities, including San Francisco and Los Angeles. Sensors are embedded in the pavement, and drivers use their smartphones to find open spots, cutting down on the wasted time and fuel that turn parking in cities into a nightmare for many drivers. But most city apps are not connected to one another via operating systems. They will be much more useful when they share data and insights and can be used in concert by city managers to take on previously unsolvable challenges.

DISCOVERING THE INVISIBLE POTENTIAL OF CITIES

When it comes to cognitive systems in cities, we're just beginning to scratch the surface of what is possible. As we go forward, data will increasingly help us spot the invisible signals being sent out by our cities. For instance, Arizona State University scientists have created a program called Hestia that makes it possible for city leaders to measure how much greenhouse gas is being emitted from specific areas of an urban landscape—right down to the street and building level. That way they can make better-informed decisions about how to reduce carbon dioxide emissions and do their part in combating climate change.[6]

In Indianapolis, where the program is being tested, Hestia gathers data from a host of sources, including traffic counts, air pollution measurements, and tax-assessor parcel information. It performs traffic simulations and building-by-building energy-consumption modeling. All of these data then go into a massive computer model of the entire city. Hestia is able to capture the patterns of emissions and display them in three-dimensional maps. It's immediately clear where the big problems are. The ultimate goal is to map the carbon dioxide emissions in all the major cities in the United States, which accounts for about 25 percent of all global CO_2 emissions.

Science must become an integral part of the rebirth of cities. The old adage, "You can't improve what you can't measure," is as true today as it ever was. What's different is that we're now getting our hands on immense amounts of information we didn't have access too before, and we are getting new tools with new measuring capabilities we could not have imagined previously. The city is becoming a living laboratory for technological innovation.

One of IBM's top city scientists is Guruduth Banavar, who led much of the work in Rio. As chief technology officer of IBM's Smarter Cities initiative, Guru spent several years traveling the world, visiting cities and interacting with their governments and business and civic leaders. Now head of industries technologies at IBM Research, Guru sees the problems and potential of cities in stark terms: It's a supply and demand equation. You've got to be able to quantify the available resources—people, capital, natural resources, land, goods, and services. And you have to understand the current and future demands for those resources. So the way to think about improving the operations of cities is through resource management, matching supply with demand.[7]

This concept is well known to people in the electric utility business. They create demand-response models with data and analytics that make it possible to manage vast grids with multiple types of supplies and myriad consumers of electricity, as well as variables such as weather and earthquakes.

Now, Guru says, we need to create much larger demand-response models for improving the livability and economic vitality of cities. He thinks of these models as cognitive engines for city management. The first step is to continuously gather vast quantities of data of all types about available resources. This would essentially be an evolving digital copy of the city in all its complexity. Analysis of the data then spots patterns: changes in human mobility, increased demand for water and electricity, and so on. Simulations help anticipate changes in supply and demand. "The system is learning as it goes," Guru says. "It's aware of the past, the current state, and the potential for the future, and it helps you manage for the present and plan for the future."

Guru grew up in Bangalore, India, and spends a lot of time in Indian cities today. He knows firsthand about traffic congestion, crowding, poverty, inadequate infrastructure, and the rapid migration of country people into urban centers. For him, this quest is personal. He's hopeful that with better systems for managing cities—cognitive systems—there will come vast improvements in mass transportation, freshwater supplies, waste-water treatment, dependable electricity, education, health care, and public safety. His vision of the cognitive city isn't about futuristic places where cars are suspended in the air and humanoid robots hand out martinis as we zip through our front doors on conveyor belts. It's about cities that improve the quality of life for billions of people and that advance the sustainability of the planet.

Today, city planners and managers focus on information that we can relatively easily capture and control. Much of this information fits neatly in the tech industry's conventional databases and is reliable. In the future, our computing systems will be able to face much more demanding tasks. They'll ingest large chunks of the world in raw form and make sense of it in all of its complexity, sloppiness, and uncertainty. In order to do this, our computers must be capable of learning. They'll be thinking all the time, gathering and analyzing, going deeper and deeper, ready to respond to humans' questions and pose questions of their own.

Up until now, we have used counting and calculating to find precise answers to our questions. In the future, how we frame the questions will define our successes. The new era of computing will make it possible for us to reshape our cities and our world based not on instinct and tabulated data but on new approaches to problem solving and questioning. With these new cognitive tools, we can grapple with the world as it really is: emergent, not deterministic. And that will enable us to respond much more intelligently and adaptively to its complexity and unpredictability.[8]

In the future, cognitive systems will monitor a city's every twitch and tremor and predict what will happen next. They will guide us to decisions and actions that produce the best outcomes for individual citizens and society. But it won't be enough to invent a new generation of tools and new ways of managing the world. The people factor must not be ignored. IBM has learned through hundreds of interactions with cities in recent years that it's essential for leaders to engage with citizens if they hope to get big things done. When they don't, they're likely to meet resistance. When they do engage, they stand a better chance of not just getting support but of enlisting the creativity and energies of the people. The many online systems for reporting potholes that cities have set up are a good example of this concept in action. When given the opportunity to report holes in pavement, citizens typically respond enthusiastically. That can save the city public works department a lot of time and expense in inspecting for potholes, and analysis of the reports can help improve preventive maintenance.

This kind of citizen engagement can have much more profound effects as well. When citizens are well informed, they understand better how a city operates and what it takes to provide the services and the physical infrastructure that they expect. Big data analytics can help bring them that depth of understanding. Perhaps then they'll be more supportive of long-term investments in service and infrastructure improvements.

In order to make our cities even more livable and effective, we'll also have to remake ourselves. To fulfill our cities' potential, we'll have to become more collaborative and less narrowly self-interested. We'll have to be more opinion seeking and less opinion offering, more interested in asking tomorrow's questions than in giving yesterday's answers.

JOURNEY OF DISCOVERY: CITIES IN MOTION

Stand on a busy city street corner in the middle of the day and you will witness a chaotic scene: thousands of people walking, getting on and off buses, descending to subways, riding in cars, and moving in and out of buildings. Where did all these people come from? And where are they going? Today, we can begin to comprehend the complexities of cities in motion and use those insights to help design the cities of the future.

Through an IBM Research project called Insights in Motion, scientists have developed analytics software that provides anonymized information about the movement of massive numbers of people. This information can be used by city managers to plan new transit routes, improve the efficiency of current transit systems, and coordinate the various transportation modes in order to make moving around in cities more convenient and comfortable. This kind of rich data about the movement of people comes as a revelation to city planners and researchers alike. "It's like a blind person for the first time opening their eyes and seeing," says Milind Naphade, leader of Insights in Motion.[9]

The Insights in Motion project is remarkable in two ways. It marks the first time that cities (including Dubuque, Iowa, and Istanbul, Turkey) have used massive amounts of data from cell-phone records to track the movement of citizens without capturing personal information, thus protecting privacy. It also illustrates the importance of developing technology in close collaboration with the people who will eventually use it. One of the key elements of innovation for the era of cognitive systems will be the willingness to use the real world, in all of its messiness and complexity, as a living laboratory for developing new technologies.

Milind grew up in what he calls the "concrete jungle" of Pune, India. He loved the fact that even though it was a large city, he could get almost anywhere he wanted to go on foot. Later, he studied for a Ph.D. in electrical engineering at the University of Illinois at Urbana-Champaign. The focus of his dissertation was on pattern recognition in multimedia content, which, it turns out, has some similarities to mapping the movements of people in cities. After working at IBM Research for several years, he got interested in using data and advanced analytics tools to solve transportation problems. His boss suggested that he find a city that would be willing to let him work with real data. Milind chose Dubuque because IBM was opening a service-delivery center there and because the city's mayor, Roy D. Buol, had laid out of vision of turning Dubuque into one of the most environmentally sustainable cities in the United States.

One of the mayor's goals there was to increase the use of the public buses. Ridership had dropped off severely over the years, which made it difficult to maintain service levels. How could this be reversed? Milind and his colleagues proposed developing a system for improving public transit in a small city. IBM Research has a program, First Of A Kind, where researchers work closely with a partner to develop technology solutions that have never been tried before. The projects are jointly funded by IBM and the partner. Milind proposed Dubuque as a FOAK. He was asked to also choose another city, a larger one in an emerging market, and, ultimately, he picked Istanbul. So they had two living laboratories that are as different as you can imagine. Dubuque has 23,000 households and only one source of public transit, buses. Istanbul is a sprawling city with 14 million residents, millions of tourists annually, and a wide range of transit options—subway, light rail, express buses, traditional buses, minibuses, and ferries.

Until now, city officials have based their knowledge of transportation activities on a wide variety of information, everything from ticket-sales data, to surveys of transit passengers, to actual counts of people on a particular bus or subway car at a particular time in a particular place. The problem is that these types of information only provide fragments of the bigger picture. A survey of people on a particular bus route, for instance, only tells you about the people who are riding the bus—not about people who are moving in the same direction at the same time via other means who might ride the bus under other circumstances.

To change the game for city managers and planners, the Insights in Motion technology draws on transit data, geospatial information, census records, points-of-interest information, and data from cell phones. By tracking the movements of thousands of people from place to place and correlating it with time and the speed of travel, the system can identify the mode of transportation people are using and figure out where they are traveling to and from, whether it's home, work, school, or shopping. Using cognitive technologies, the system learns what their needs and expectations are.

The team started in Dubuque. In addition to gathering mobile-phone location data from telecom carriers, they also recruited 1,000 volunteers who own smartphones. The high-end handhelds are equipped with GPS and accelerometers, which make it possible to track the volunteers as they travel around the city with pinpoint accuracy. The team developed an application for the smartphones that would enable the volunteers to use them to navigate the transit system.

Their task was challenging. They had to build a system that could, in a sense, "understand" what a city is, what people are, what people do, and how they move from place to place. They needed a digital model of a city that they could experiment with. So they built a framework of knowledge about each individual's activities, including detecting meaningful locations, segmenting trips, calculating the duration of stays, identifying the purpose of each trip, plotting origins and destinations of each trip, tracking the time of day, and specifying the mode of transportation. They even estimated the carbon footprint of each trip. Then they aggregated all of the information about individuals to generate citywide patterns.

The team used the results to optimize the routes and schedules for the city's bus system. The objective was to minimize the sum of operator costs, user costs, and unsatisfied demand costs for the entire network. Costs aren't just expressed in dollars. For users, for instance, they include factors like waiting, walking, and driving a car. Dubuque is now trying the information out with two new bus routes. "Having the data is crucial. You don't have to operate on tea leaves," says Chandra Ravada, director of the transportation department for Iowa's East Central Intergovernmental Association. "You know where people are going. You can change things based on that. You're designing your system not on somebody's opinion but based on facts."[10] The goal is to reduce operating expenses by 40 percent, meet 37 percent more demand, reduce average commuter time by 60 percent, and reduce per-traveler combustion emissions by 40 percent.

Milind and his team took the lessons from in Dubuque and applied them in Istanbul. The task there was much more complex. There were so many more people and modes of transportation. Also, in Istanbul, they didn't track volunteers with smartphones. They had to rely on less precise records from regular mobile phones. But the technologies they had used in Dubuque also worked in Istanbul. The city's transit authority, Istanbul Transportation, is using the Insights in Motion tool to help design feeder bus routes connecting to the city's new subway lines.

Having these two cities to experiment in was incredibly helpful for Milind and his team. When researchers don't have a real-world situation to interact with, they can't easily identify the constraints that products and services created using their technologies will encounter when they're launched. The volunteers in Dubuque provided valuable feedback on the shortcomings of the smartphone application, which the team used to improve it. In Istanbul, Milind came to appreciate the importance of personal privacy and securing data. Because of privacy concerns among the city officials there, the IBMers worked on the data only when they were in Istanbul. The experience made them very thoughtful about designing security and privacy features into all of the analysis systems they build.

At the highest level, Milind believes that Insights in Motion has tremendous potential to alter the relationships of cities and their citizens. "One thing I think about is how we have become slaves of the infrastructure rather than having the infrastructure work for us," he says. "Cities should help people live their lives, not get in the way."