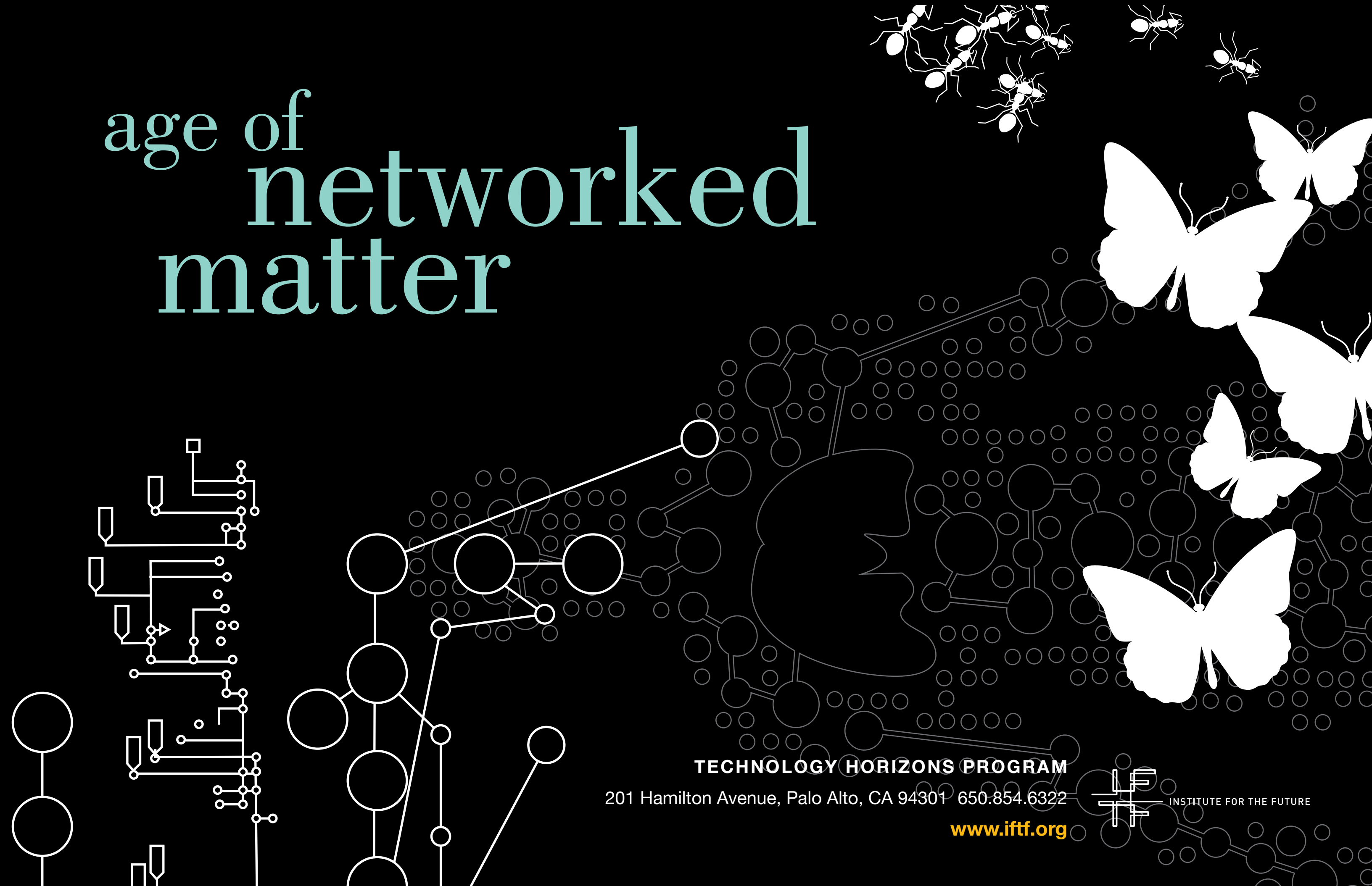
age of networked matter



TECHNOLOGY HORIZONS PROGRAM

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www.iftf.org

INSTITUTE FOR THE FUTURE

It will be an era
of huge possibility, daunting pitfalls,
and high weirdness.

It is The Coming Age of Networked Matter.

The age of networked matter

“The world is full of magic things, patiently waiting for our senses to grow sharper,” wrote poet W. B. Yeats. What we see, what we experience, and what we can control, are infinitesimally small pieces of the whole picture. We not only miss the forest for the trees, but we miss the roots, the soil, and the other plants and animals. Until now, we have been mostly blind to the systems, and networks of systems, that underpin our physicality. But over the next decade, a confluence of breakthroughs in physics, engineering, biology, computation, and complexity science will give us new lenses to observe the wondrous interconnections surrounding us and within us. It is in those systems—from the microbial to the planetary—where the potential truly lies to improve our lives, restore our planet, and understand our universe.

In the future we’re moving toward, we won’t only observe complex systems, we’ll also modify and even create them in vivo and with purpose. The components of these systems will range from household objects with networked eyes and ears to tiny robots that behave like swarming bees to sentient cities that converse with context-aware coastlines. Whether it’s through nanotechnology, gene therapy, geo-engineering, or yet-to-be discovered interventions, we will interact with these natural and artificial objects to affect change at the system level. We will attempt to program our world for stability and resilience, even as we struggle with the unintended consequences of tweaking the knobs of reality.

Our map reflects three time horizons

Propelling ourselves past the present, beyond the near future, and into The Coming Age of Networked Matter, we begin in the current era of Abundant Data, travel through the Internet of Things, and, by the end of the decade, arrive at the Age of Networked Matter.

ABUNDANT DATA

The diffusion of sensors, communication devices, and processing power into everyday objects and environments is unleashing an unprecedented torrent of data. These continuous data streams are creating a window into many complex systems and interactions at extraordinary resolution.

THE INTERNET OF THINGS

A multitude of objects—from cars to coffee cups—will be instrumented with unique identifiers like RFID chips as well as computation and communication systems to connect to the Internet. Cyberspace will cease to be a place we go to through our personal computers and will become an overlay on top of our existing reality.

THE AGE OF NETWORKED MATTER

The difference between bits and atoms will blur as the connections among all things become evident. Using the tools and techniques of systems thinking and design, we will transform how we think about ourselves and our place in the world, even as we face the tensions of having unprecedented control over matter at all scales.

Systems thinking across four scales

In the Age of Networked Matter, we must all become adept systems thinkers. Systems thinking emerged as a formal practice in the 20th century, drawing from cybernetics, control theory, and ecology, but its roots as a science for understanding the world go back much farther. Indeed, Aristotle captured its essence in 350 BCE: “The totality is not, as it were, a mere heap, but the whole is something besides the parts.” A system is a group of things whose interactions result in particular effects or behaviors that are very different than that of each part. The behavior exists within the structure of the system itself. Sometimes these systems can generate coherent new structures and patterns, evolve, and even learn.

One key to unlocking systems is an acute sense of scales—from the scale of ant colonies to neural networks to complex weather patterns—and our relationship to them. In the Age of Networked Matter, the systems we illuminate, modify, and design will frequently be cross-scale. For example, the number of bacteria living inside each of us outnumber human cells ten to one. And that unseen bacterial system, called the human microbiome, is integral to the health of a much larger system, our body. With that in mind, we’ve organized our map not only along a time horizon but also by four scales.

This map is a guide to how the network will take shape over the coming decade. Use it to shift your perspective and aid your search for leverage points to catalyze change across scales.

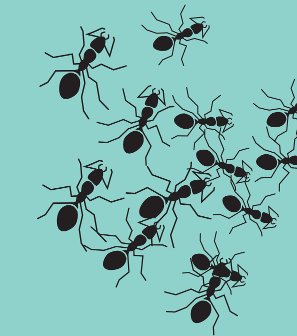
THE PLANETARY SCALE is ultimately where our decisions come home to roost. Faced with uncertainty and volatility tied to the likes of global warming, environmental devastation, and unpredictable pandemics, we need to think globally and act locally, and vice versa.

THE CITY SCALE is shaped by massive urbanization, most of which will occur in less industrialized nations over the next 30 years. Dense urban centers will become the new machines for living.

THE PEOPLE SCALE is where we spend most of our time. “We shape our tools and thereafter our tools shape us,” as media theorist Marshall McLuhan famously said. And of course, we are only one small part of many much larger systems.

THE MICRO SCALE ranges from the nanoworld—where properties of materials become quite surprising—to the genes, proteins, and cells that are the building blocks of life, to microelectromechanical systems smaller than the period at the end of this sentence.

Technology stories driving toward the age of networked matter



To get to the Age of Networked Matter, we need to move through several time horizons. Six technology stories will help us move through the current era of Abundant Data, transition from the imminent Internet of Things, and move us into the Age of Networked Matter.

Only when industry standards emerge and suites of different underlying technologies begin to sync up and work together in rhythm will we see this movement toward the Age of Networked Matter take hold. We outline these stories here and include for each story a list of the core technology research areas that matter.

THE WHOLE EARTH INSTRUCTION MANUAL

from computer science › **to systems science**

Building the early Internet of Things will require a relatively simple cause-and-effect approach to systems building. Already, emerging platforms like If This Then That are allowing everyday people to connect data streams using simple digital recipes. Yet, as the web of networked devices and systems expands, the complexity of these individual recipes will increase exponentially, and networked processes will begin to interfere with one another.

In this environment, the underlying electronics will be far easier to understand than the systems and objectives they are driving. Effectively managing this complexity will require an emphasis on complex systems thinking and design. Indeed, underlying advances in systems science will be central to the transition beyond the somewhat robotic Internet of Things into the more organic Age of Networked Matter.

- Systems Science
- Complexity Science
- Systems Biology
- Swarm Engineering
- Bioinformatics
- Nanoscience

BETTER NETWORK NERVOUS SYSTEMS

from ad hoc › **to hierarchical network topologies**

As billions of new devices begin to come online, each will contribute to a growing burden on processing systems. While computational power is increasing dramatically over time, it will always be limited by fundamental physical and energy constraints. In this environment, it is not practical to connect every new device to all of the billions of other possible connected things in order for it to collaborate effectively within its networks.

The human nervous system faces a similar problem, and the central and peripheral nervous systems have evolved to effectively process and prioritize information. Similarly, network topologies for connected things will increasingly rely on hierarchies.They will range from simple peripheral sensors and actuators and intermediate collection and combination points all the way up to central cloud-based processing and sensemaking.

- Network Science
- Network Virtualization
- Network Intelligence
- Data Analysis
- Ubiquitous Sensors
- Cloud-based Supercomputing

VIRTUAL INTUITION

from rigid data triggers › **to probabilistic data ecologies**

Today's connected systems rely on precise measurement of key data points to trigger specific responses. For example, the digital GlowCap measures how often a medication is being taken from a prescription bottle. If patients miss one of their prescribed doses, the GlowCap is triggered to take a series of steps to attract their attention, up to sending text-message reminders.

This kind of rigid data trigger will be impractical, though, as systems are increasingly designed to combine multiple data flows in order to make inferences, or best guesses, about how to behave. Data is likely to become both more portable or "liquid" across many uses and to be weighted probabilistically as it is compared to other available data. In this environment, the relevant data that can best be verified will carry the most weight.

- Inference Software
- Ubiquitous Sensors
- Data Analysis
- Visualization Technologies
- Cloud-based Supercomputing

ENGINEERING THE INVISIBLE

from macroscale machining › **to nanoscale assembly**

Long hyped as the next big thing in small things, recent breakthroughs in nanoscience along with rapid progress in materials science and biotechnology are finally leading to myriad new devices at the microscale. Micro-electromechanical systems (MEMS) are functional micromachines that use mechanical gears, pumps, and switches to sense environmental conditions or even serve as motors in tiny robots. Xerox's Palo Alto Research Center has demonstrated a machine that can precisely print MEMS and sand grain-sized computer "chiplets" right onto surfaces. Incorporating the technology into 3D printers will enable objects to be built layer-by-layer with tiny computers and mechanisms integrated into their structures.

Simultaneously, advances in the biological sciences will allow us to use nature's own materials and processes in nanoscale manufacturing and computer architectures. Neuromorphic engineering mimics the signal processing architectures of animal nervous systems to design better computers and robots while "DNA origami" involves programming the molecule to fold itself up in specific shapes. Biology will be a true engineering field where genes, proteins, and cells can be snapped together like Tinkertoys to build living systems. Over the next decade, the most fertile ground for experimentation will be at the intersection between the synthetic and biological.

- MEMS
- Nanoengineering
- Synthetic Biology
- Biomimicry
- Single Cell Imaging
- Molecular Self-assembly

RETHINKING NETWORK POWER

from dumb electricity grids › **to smart energy harvesting**

Until now, the vast majority of connected devices have needed to be plugged into a wall socket either to charge their batteries or to work at all. Increasingly, networked things will pay attention to their own energy usage and coordinate across the emerging Smart Grid patchwork to use energy in cheaper and more efficient ways.

However, the grid-based approach will be increasingly impractical for many of the tens of billions of additional networked things. Moving forward, expect a number of additional novel energy-harvesting techniques to find niche applications. These include a spectrum of technologies ranging from wireless energy transmission to harvesting the energy from ambient motion and vibrations to the dramatic proliferation of embedded solar cells.

- Wireless Energy Transmission
- Next-generation Capacitors
- Solar Technologies
- Metamaterials
- Kinetic Energy Harvesting
- Fuel Cell Technologies

THE WEB AND THE WEB OF LIFE

from digital networks › **to connections across substrates**

Digital systems will increasingly be built to interface with other types of natural networks. For example, early research into brain-computer interfaces has already begun to shed light on the ways digital systems can effectively connect to people's neurological systems. This has allowed rapid progress toward tools that allow people who are disabled to control their computers, or even robotic prosthetics, directly with their brains. Researchers have also remotely controlled cockroaches via electrodes implanted in the bugs' brains.

On the horizon are many more bridges between artificial and natural networks within our bodies and in the world at large. As nanotechnologies enter medical applications, for example, expect connected devices to begin to "nudge" internal processes to increase both health and performance. At the scale of natural environments, we will uncover nature's hidden networks such as the underground strings of fungi through which trees transfer nutrients, a system some ecologists have dubbed a "wood-wide web." Through bio-artificial interfaces, we will tap into these natural networks to monitor and manage the well-being of our oceans and forests.

- Bioinformatics
- Network Science
- Brain-machine Interfaces
- Microbial Genomics Technologies
- Biomimicry
- Synthetic Biology

Keep the future weird

"Keep Our City Weird" is a proclamation by residents of Austin, Portland, and other cities around the globe that the citizens there not only accept, but welcome unusual, offbeat, and fringe thinking and lifestyles. The genre and practice of science fiction is a similarly inviting space in our minds where writers, and readers, are encouraged to explore the strange implications of future technology. As evidenced by this map, the Age of Networked Matter will undoubtedly be a startling, strange, and transformative future where people, objects, and all matter is connected. That's why IFTF's Technology Horizons Program commissioned six leading science fiction authors to share their visions of what the Age of Networked Matter could look like, feel like, and mean for the human condition. In the resulting short story collection, titled *An Aura of Familiarity: Visions From the Coming Age of Networked Matter*, the authors describe six internally-consistent future worlds in the form of provocative, emotional, and immersive forecasts that hint at how social, cultural, economic, and political shifts brought about by networked matter could redefine life in the next decade and beyond. To keep the future weird, immerse yourself in possibility by working with science fiction as a forecasting tool.

IMMERSE
yourself in a story

After you've explored the forecasts on the inside of this map, dive into one of the science fiction stories in the companion book *An Aura of Familiarity: Visions From the Coming Age of Networked Matter*. Use the summaries below to select a story and focus your attention on the future technology capacities, disruptions, and dilemmas it presents.

REMIX
the story

Each story imagines provocative new tools, services, or changes to the systems that surround our lives. Pick up where the authors' world ends and invent a different use for one of the key technological capacities described in the story. In other words, remix the story and apply the technology capabilities to different arenas of daily life and experience: shopping, education, citizenship, health, work.

MAKE
your own future

Start with one of the signals from any of the three time horizons on the inside of the map and prototype how the concept could play out as it becomes part of our daily lives. Or, build out one of the forecasts from the Age of Networked Matter and write a short pitch for your own science fiction story. Use your story as an inviting space to explore strange possibilities and disruptive transformations for yourself, your organization, or your community.

JUMP
scales to get weird

The Age of Networked Matter will offer surprising connections between scales and systems, like micro-scale interventions that catalyze planetary-scale responses. Find the novel ways systems are interconnected in your story. Think beyond the human scale to find what really matters. Look for the unexpected leverage points that have the potential to catalyze change across scales.

MADELINE ASHBY'S › Social Services

A social worker struggles to rehabilitate one juvenile delinquent, where truancy means rebelling against the transparencies of a surveillance-saturated world.

CORY DOCTOROW'S › By His Things Will You Know Him

A funeral becomes an occasion for a son to understand his father's life through the clutter he leaves behind, with help from a new technology to add digital meaning to physical stuff.

WARREN ELLIS' › Lich-House

An assassin constructs a bubble of firewalls to defeat the defenses of a sentient home constructed from all-seeing, superconnected cellular building blocks.

RAMEZ NAAM'S › Water

When products on store shelves connect directly to our neural implants as we walk by, marketing turns into a personal, persuasive, and irresistible endeavor.

RUDY RUCKER'S › Apricot Lane

The Quarpet platform offers anyone a networked life of gossiping shoes, attention-sensing furniture, and automatic micro-payments everytime you enjoy anything. Just don't run out of money.

BRUCE STERLING'S › From Beyond the Coming Age of Networked Matter

When a California startup's experiment in hacking the hive mind of an insect colony threatens to unravel the fabric of reality, there's no looking back.

ABUNDANT DATA

SHORT-TERM | Imminent rapid developments

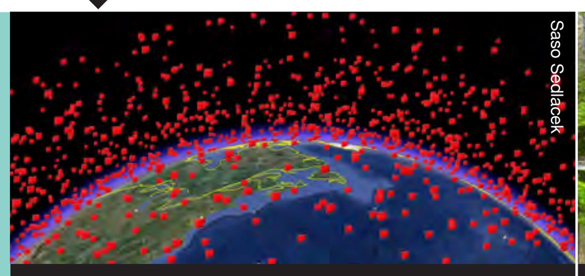
INTERNET OF THINGS

MEDIUM-TERM | An evolution beyond what we see early signs of today

age of networked matter

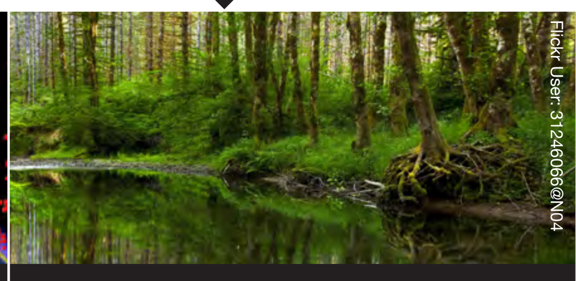
LONG-TERM | Emerging possibilities beyond the next decade

PLANETARY SCALE



Sasa Sestilleti

TRACKING SPACE JUNK The U.S. military's SpaceView project is a network architecture and collaborative platform for amateur astronomers to help track more than 500,000 pieces of orbital debris that put satellites at risk.



Flickr User: 91240696@N04

TAKING THE RAINFOREST'S VITAL SIGNS In the Atlantic Rainforest Sensor Networking Project, sensors "take the vital signs of the rainforest" as a new way to study the interactions between climate and various ecosystems.

University of Hawaii

COMMERCIAL SHIPS AS TSUNAMI SENSORS Researchers from UH Manoa and NOAA showed that GPS data from commercial ships can reveal tsunami activity even when the waves are just a few inches high in the open ocean.

World Wildlife Fund

CONSERVATION DRONES With a grant from Google, the World Wildlife Fund is deploying a system of drones, RF tags, and analytical software to aid rangers in Africa and Asia in monitoring wildlife to protect against poachers.

global simulation

TOWARD TEST-AND-LEARN

As pervasive sensor networks open up new vistas on the world, every object, every interaction, and every observation will become a piece of data to populate myriad models of planetary systems at all scales. Driven by breakthroughs in complexity science, these models will form the basis of a real-time simulation of the entire planet. Planetary dashboards will be used to study all kinds of events—from climate change and species acclimatization to economic crises and social upheaval—and simulate interventions before acting. Access to these more-real-than-real models and interpretation of their output will complicate power dynamics and agency as we move into what computing pioneer Alan Kay calls an era of simulation literacy.

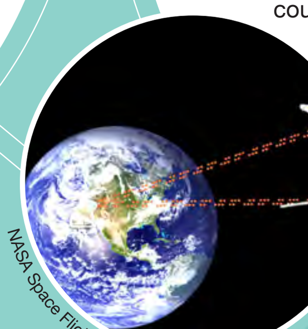
Wikimedia Commons

WHOLE EARTH SIMULATOR The Swiss Federal Institute of Technology has proposed a massively collaborative project to build a Living Earth Simulator that would model techno-socio-economic systems at a global scale.

interplanetary internet

TOWARD A NETWORKED SPACE AGE

As public foundations and private concerns launch entrepreneurial ventures in space around medicine, manufacturing, surveillance, and tourism, new technology will be deployed to network space vehicles, satellites, robotic explorers, and eventually human habitats on other planets. Inexpensive, low-mass "pico satellites" will serve not only as sensors orbiting other planets but also as network routers and bridges in places where continuous end-to-end connections are unlikely. New kinds of protocols will move data "hop by hop" to deal with the massive distances, disconnections, and errors that will be par for the course in this "Interplanetary Internet," a term coined by terrestrial Internet pioneer Vint Cerf. Advances in this disruption-tolerant networking technology will also improve terrestrial networking, especially in extreme environments such as deep ocean trenches, disaster situations, and remote outposts.



NASA Space Flight Systems Mission Directorate

SPACE NET An astronaut used a prototype Interplanetary Internet to control a terrestrial robot.

Flickr User: wwarby

DO YOU SPEAK DOLPHIN? The Wild Dolphin Project and Georgia Tech computer scientists are creating a dolphin and human-friendly communication system and pattern recognition software to decode dolphin sounds.

crossing the semiosphere

TOWARD INTERSPECIES COMMUNICATION

As we recognize that humans are not the most important node in the planetary network, we'll increase efforts to communicate with other intelligent species on Earth. As anyone who's visited Sea World knows, dolphins are adept at responding to human language—especially when the reward is a tasty fish treat. But can we learn to speak dolphin? Already, researchers are developing a computer-based tool that translates dolphin sounds into requests of their human observers. Scientists are also trying to crack the linguistic code of the low-frequency calls that elephants use to maintain order in their clan-based social networks. As such research continues, the human-centric approach of trying to teach other species our languages will mostly fall by the wayside. More likely is the development of constructed languages, known as "con-langs," that various species can learn together.

networked sensorium

TOWARD EXTENDED SELVES

As the world is instrumented with billions of networked cameras and sensors on the ground, in the sky, and in our bodies, we will have a visual, auditory, and eventually tactile connection to every location on the planet across multiple scales. This visceral extension of our bodies will result in a kind of planetary proprioception, altering our sense of place in relation to every other place. Meanwhile, a deeper understanding of how our brain manages internal and external stimuli will lead to new totally immersive, multisensory interfaces. Networked integration of this new extended sensorium will spur us to reconsider where our own bodies end and the rest of the world begins. Such telepresence networks that enable us to be multiple places at once could also be the infrastructure for a surveillance system that puts Jeremy Bentham's Panopticon penitentiary to shame.

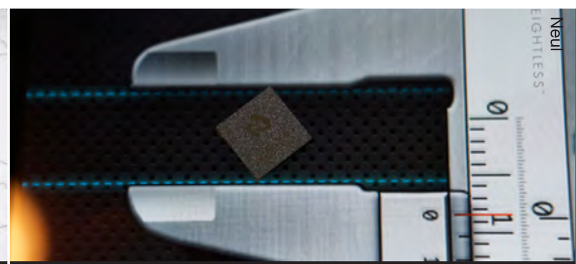
University College London

WHERE AM I? Neuroscientists have shown that ambiguous or intentionally misleading sensory data can change the perception of body ownership and even where the conscious mind is located in space.

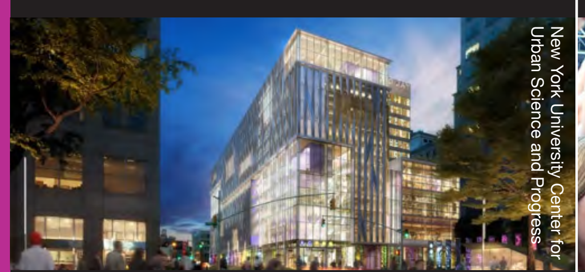
CITY SCALE

IBM Social Media

DATA EXHAUST MEETS TRANSIT PLANNING In Istanbul, IBM helped city planners redesign the bus network based on mobile phone location records.

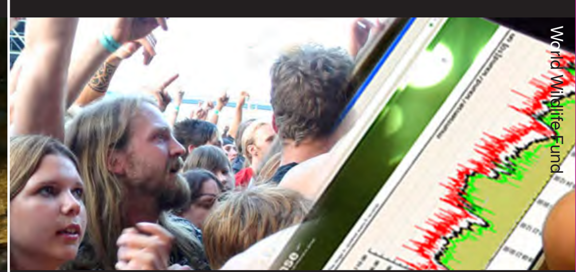


WHITE-SPACE RADIOS The UK's Weightless Special Interest Group has developed a chip that uses unlicensed low-frequency TV airwaves for wireless machine-to-machine communications.



New York University Center for Urban Science and Progress

CITY SCIENCE Numerous academic institutions have launched programs like New York University's Center for Urban Science and Progress to study complex urban systems through a data lens.

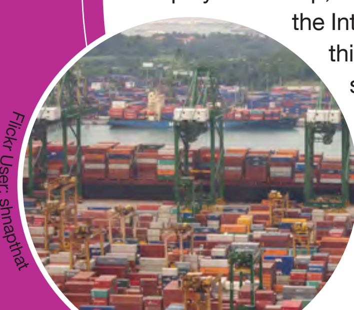


URBAN SENSOR WEBS Netherlands-based startup Munisense provides sensor networks and data analysis for the management of water, energy, noise, and public lights in cities.

matter routing

TOWARD PREDICTIVE LOGISTICS

As physical objects come alive and begin to share data, complex logistics, and transportation systems will disaggregate and become more like the packet-switched networks underlying the Internet itself. Objects with embedded sensing, computation, and communication will be tracked through a smart supply chain. Robot-powered warehouses will have direct links to autonomous delivery vehicles, including swarms of drones, and intelligent algorithms will play traffic cop, in effect enabling matter to route itself to us. As with the Internet, disruptions will be routed around, making this model more resilient than conventional hub-and-spoke distribution models. Algorithms will become capable of reliably predicting where and when resources will be needed. Eventually, just-in-time matter routing will be replaced by predictive logistics. Delivery systems will make their own plans for how to navigate supply chains.



Flickr User: pjmoss

INSTRUMENTING THE SUPPLY CHAIN REWE Group has electronically tagged its 250,000+ container distribution system to create a logistics dashboard representing some six million data points daily.

Wikimedia Commons

SMART BUILDINGS Building information models (BIMs) that sense and control every aspect of a structure's operations enable programming of building behaviors, such as automatically opening windows and cutting HVAC at ideal times to manage microclimates and save money.

the urban crucible

TOWARD CITY-SCALE INNOVATION

Urban growth and renewal will present a challenge-rich landscape for businesses, governments, and citizens within domains like health, security, energy, education, and transportation. Cities are where people and groups faced with challenges will connect with problem-solvers—from the research and entrepreneurial communities but also from the DIY and maker cultures. These collaborations and partnerships will be supported by legacy assets like existing buildings and infrastructure but also be enabled and amplified by new technology such as wireless networks, sensors, and personal computing devices. The resulting networks of people, problems, solutions, and systems will ignite a supernova of innovation in urban settings. Meanwhile, pervasive and seamless computational platforms will be prototyped and piloted by governments and companies facing the prosaic challenge of deploying and managing a network of trillions of objects in the close confines of the digital metropolis.

Flickr User: Public Radio

BEACON (Berkeley Atmospheric CO2 Observing Network) UC Berkeley has installed the first urban sensor network to collect neighborhood-by-neighborhood C02 data in Oakland.

sentient cities

TOWARD MUNICIPAL INTERNETS

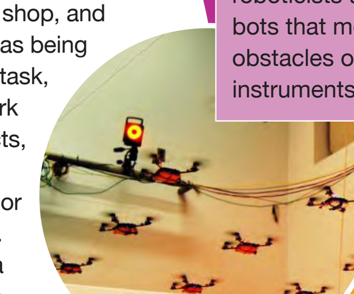
While much of the current Internet's value is in overcoming geographic distances, networked applications and services at the hyperlocal level will become the locus of urban innovation. With an infinite "connectome" of possible links between people, roads, buildings, and raw sensor data, the city will be recognized as a dynamic network far larger and more complicated than today's entire Web. City services will be increasingly data driven to maximize resources, increase growth, and reduce costs. From mapping the availability of healthy food in poor areas to enabling citizen participation in traffic management, municipal internets will change our relationship to urban centers as networked matter reveals the flow of people, things, and data through our built environment.

social robots

TOWARD ROBOT CO-DEPENDENCE

Today, the term "social robot" usually refers to autonomous robots that interact with humans under rules defined by society. As robots become pervasive mobile nodes on the network, they will become socially engaged with each other. Cloud-connected robots will join a social network to meet "like-minded" bots, talk shop, and pass along knowledge learned through experiences such as being taught by a human how to set a table. After mastering the task, the robot will upload its new knowledge to its social network for other robots to access and improve upon. Paths, objects, techniques will all be shared, enabling robots to make informed guesses about, say, how to grasp a wine glass, or that one should avoid toddlers when chopping firewood. Groups of simple but social robots will collaborate on a multitude of tasks, shuttling people throughout dense urban centers, or forming ad-hoc wireless networks in the sky. Their collective behavior, greater than the sum of their silicon parts, will be based on the emergent behaviors observed in ant colonies, bird flocks, and animal herds.

SWARMBOTICS University of Pennsylvania roboticists unleashed a swarm of small flying bots that move in tight formation without hitting obstacles or each other, and even play musical instruments as an ensemble.



KMel Robotics

organizations as algorithms

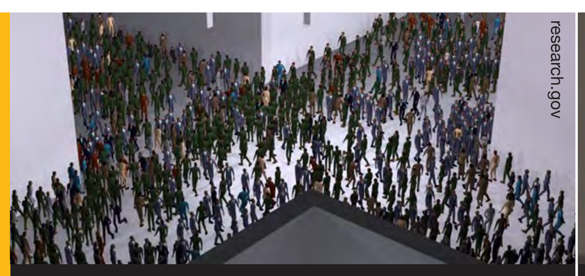
TOWARD COMPUTABLE WORK

Traditional computing is built around human users providing a problem framework and algorithms and getting back an answer. The emerging discipline of human-based computation flips this relationship, with computer systems designed to task people to solve problems. We will see software tools that put supervision of complex work processes into play at the touch of a button. For example, a single software program developed to build a house could place and track supply orders, coordinate workers, file government paperwork, and contract for site cleanup and landscaping. Organizations in this environment will provide value by working out optimal processes for getting things done. These processes will often be run directly on the platforms created for coordinating networked things.

Flickr User: To...

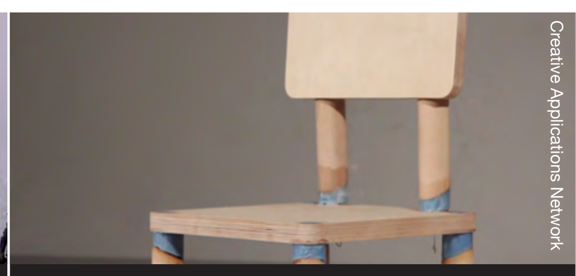
PEOPLE ROUTING Workers at C&S Wholesale Grocers wearing headsets are directed through the warehouse by a computer speaking in several languages.

PEOPLE SCALE



research.gov

PREDICTIVE BEHAVIORS University of Birmingham researchers have developed an algorithm that can predict an individual's movements by combining his location history with data from his online social connections.



Creative Applications Network

DRM CHAIR Swiss university students have designed a chair that self-destructs after eight uses as a sardonic commentary on digital rights management.

Cataphora

BEHAVIOR MINING Software from Cataphora mines data trails to map employee relationships and influence inside organizations, identifying high-performing teams or aberrant behavior.

MyRobots

FACEBOOK FOR ROBOTS MyRobots is a cloud robotics platform meant to offload computation and provide services on demand to robots that join the network.

Canon U.S.A. Inc.

ISPY German security researchers hijacked a WiFi-enabled Canon DSLR camera to turn it into a remotely operated CCTV camera.

DRM overrides

TOWARD OWNER CONTROL

Within a decade, trillions of networked physical objects will be in use, but what users do with the devices or their data might not be entirely up to them. Already, what you can do with certain medical devices varies depending on whether you are a patient, specialist, caretaker, or insurance provider. Digital rights management (DRM) technologies give manufacturers a way to control a device (and software) even after it has been purchased. Even worse, the DRM and its processes are hidden from the user, making it easier for malicious parties to hijack devices without being detected. With owners already looking for ways to override DRM technologies, networked products that prevent us from using them in the ways we want, or whose secrets put us in danger, are likely to fail in the marketplace.

MEME WARFARE The U.S. Defense Department solicited research proposals "to develop a new science of social networks" to understand patterns of information and opinion flow through social media.

Flickr User: SeeJake

networked chatter

TOWARD A SCIENCE OF SOCIAL CONTAGION

Social network theory will become an experimental science with opportunities for instant global experimentation. As the online and offline worlds blend, our digital trails reveal more and more about who we are. Analysis of those trails will identify the most persuasive, and persuadable, individuals in any network and also the chain by which to reach them. By applying epidemiological models to these social networks, we will be able to insert memes—ideas that behave similarly to viruses—into culture to achieve desired outcomes. It will become possible to predict and design the attitudes and actions of society at every scale, from individual buying habits to mass beliefs. While social networking may still be seen as a fun and useful way to connect with friends, untold numbers of precisely targeted campaigns of influence, coercion, and control will be battling for mindshare behind the scenes.

SRL.org

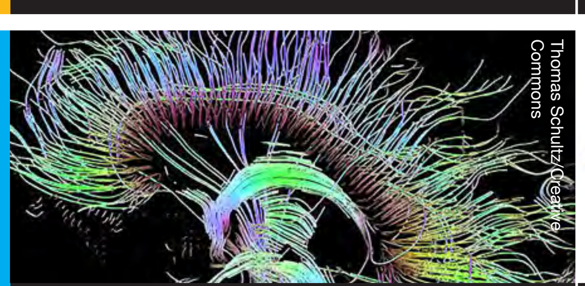
ART OF WAR Machine art group Survival Research Laboratories stages dangerous performances with exquisitely engineered lethal robots— under only a modicum of control.

the sorcerer's apprentice

TOWARD MANIACAL MACHINE MOBS

One morning in 2012, a rogue algorithm triggered thousands of erroneous trades on the New York Stock Exchange. The so-called "zombie software," that was accidentally reactivated, lost brokerage firm Knight Capital Group $440 million in 30 minutes. And it wasn't the first time a robotic trader went awry on Wall Street. These kinds of fiascos sound like Goethe's 1797 poem "The Sorcerer's Apprentice" applied to software and big data. No surprise that network engineers have used the term Sorcerer's Apprentice Syndrome to describe an obscure network protocol flaw in which data packets can replicate uncontrollably and cause systems to spin out of control. But what happens when algorithms have dominion over the physical world as well? In 2007, a robotic antiaircraft cannon tested by the South African National Defense Force experienced a software glitch causing the weapon to open fire uncontrollably, killing 9 and wounding 14 people. Fortunately, this was an isolated incident, involving a very lethal weapon. But it's still a harrowing reminder that as we program ourselves out of the loop, we need to keep an eye out for bugs in the system like our life depends on it. Because it will.

MICRO SCALE

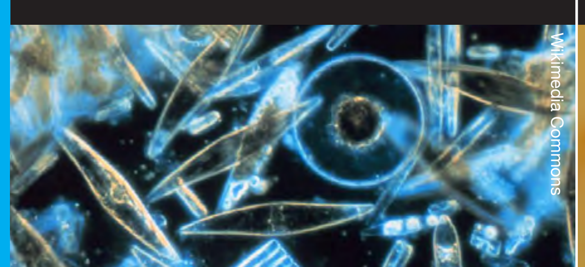


Thomas Schultz/Wikimedia Commons

MAPPING THE ACTIVE MIND Funded by the U.S. government, the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) project is a massive project to create a map of human brain activity.

Autodesk Research

NANOCAD Autodesk, maker of industry-standard computer aided design (CAD) tools, has launched Project Cyborg, a suite of cloud-based design tools for "programming matter across domains and scales."



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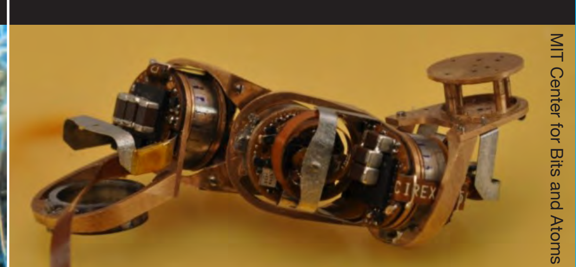
TINKERTOYS FOR LIVING SYSTEMS The International Open Facility Advancing Biotechnology (BIOFAB) has established a public domain collection of DNA sequences and associated data for thousands of genetic parts.



MIT Center for Bits and Atoms

SHAPESHIFTING ROBOT MIT's caterpillar-sized Milli-Motein (millimeter-scale motorized protein) robot is a chain of programmable mechanisms that folds itself into arbitrary shapes.

ROSETTA STONE FOR BACTERIAL COMMUNICATION Princeton University professor Bonnie Bassler studies how bacteria use chemical group behavior.

microbial services

TOWARD INTENTIONAL BIOLOGY

Advances in the field of systems biology—where the focus is on a holistic view of biology—will lead to the ability to not only genetically re-engineer existing life but also create new organisms that crank out medications, detect and eat toxic waste, and produce renewable fuels. Parallel with the development of this synthetic biology, cracking the code to understand how microbes chemically chat and band together will show us how to bend the lines of bacterial communication, which could yield significant advances in antibiotics, sterile materials, and food safety. Combining synthetic biology with a Rosetta Stone for deciphering bacterial communication could ultimately result in designer microbial services—networked bacteria working together as cellular factories, health interventions that work from the biome up, and even swarms of bugs monitoring our environment and trying to clean up our messes.

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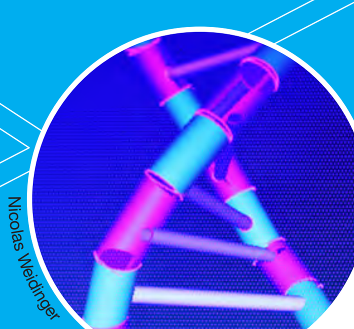

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BIOLOGICAL COMPUTING Stanford bioengineers have built a functioning transistor out of DNA and RNA, dubbing the device a "transcriptor."

adaptive atoms

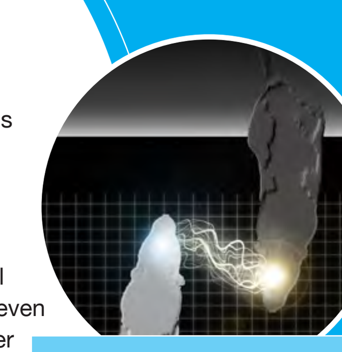
TOWARD PROGRAMMABLE MATERIALS

In 1959 physicist Richard Feynman, in a lecture titled "There's Plenty of Room at the Bottom," raised the possibility of manipulating matter at the smallest scale. Over the next decade the cross-disciplinary fields of nanoengineering, info-chemistry, and materials science will deliver ant-sized robots mass-produced like computer chips, metals that can change form with the push of a button, and fabric with embedded intelligence. These devices will become even more interesting when they work collectively to achieve macro-scale effects—for example, when a swarm of modular nanobots self-configures to create a much larger machine. Perhaps the building blocks of such morphing materials will communicate to coordinate behaviors through tiny radios made from metamaterials, biochemical signaling, or even bacteria to shuttle messages back and forth.

synthetic telepathy

TOWARD A HARDWIRED HIVE MIND

A "global brain"—all the minds on Earth linked in a self-organizing system—has been prophesied since the 19th century by philosophers and scientists. While the Internet is a step in that direction, it pales next to the mind-spinning potential of synthetic telepathy, in which brains are directly linked. Bioengineers have translated brain signals into machine-readable forms (and back again) for the neuroprosthetics that allow paralyzed individuals to control computers and robot arms. Perhaps individual brains (or even subsystems of brains) could eventually be linked together to better control physical systems, solve problems, or even create art. Even farther out, spare cognitive "cycles" of networked brains could be shared for processor-intensive tasks, further blurring the line between individual brains and collective minds.



Duke University

BRAIN-TO-BRAIN INTERFACE Duke University researchers have electronically linked the brains of two rats, suggesting the possibility of an "organic computer," which could allow sharing of motor and sensory information among groups of animals.

ABOUT THE INSTITUTE FOR THE FUTURE

The Institute for the Future is an independent, nonprofit strategic research group celebrating 45 years of forecasting experience. The core of our work is identifying emerging trends and discontinuities that will transform global society and the global marketplace. We provide our members with insights into business strategy, design process, innovation, and social dilemmas. Our research generates the foresight needed to create insights that lead to action and spans a broad territory of deeply transformative trends, from health and health care to technology, the workplace, and human identity. The Institute for the Future is based in Palo Alto, California.

ABOUT THE TECHNOLOGY HORIZONS PROGRAM

The Technology Horizons Program combines a deep understanding of technology and societal forces to identify and evaluate discontinuities and innovations in the next three to ten years. We help organizations and communities develop insights and strategic tools to better position them for the future. Our approach to technology forecasting is unique—we put people at the center of our forecasts. Understanding humans as consumers, workers, householders, and citizens allows IFTF to look beyond the technical capabilities and identify the value in new technologies, forecast adoption and diffusion patterns, and discover new market opportunities and threats, as well as anticipate how we will live, work, and connect with one another in the coming decade.

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