WORLD GOVERNMENT SUMMIT
القمة العالمية للحكومات

Advanced science and the future of government

Robots and Artificial Intelligence

Genomic Medicine

Biometrics

Written by

The Economist Intelligence Unit

WORLD GOVERNMENT SUMMIT THOUGHT LEADERSHIP SERIES

Contents

Foreword

Advanced science and the future of government is an Economist Intelligence Unit report for the 2016 World Government Summit to be held in the UAE. The report contains three chapters:

1. Robots and Artificial Intelligence
2. Genomic Medicine
3. Biometrics

The findings are based on an extensive literature review and an interview programme conducted by the Economist Intelligence Unit between September-December 2015. This research was commissioned by the UAE Government Summit. The Economist Intelligence Unit would like to thank the following experts who participated in the interview programme.

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Introduction

Governments need to stay abreast of the latest developments in science and technology, both to regulate such activity, and to utilise the new developments in their own service delivery. Yet the pace of change is now so rapid it can be difficult for policymakers to keep up. Identifying what developments to focus on is a major challenge. Some are subject to considerable hype, only to falter when they are applied outside the laboratory.

Why focus on robots and AI, genomic medicine, and biometrics?

This report focuses on three advances which are the subject of considerable excitement today: robots and artificial intelligence (AI); genomic medicine; and biometrics. The three share common characteristics. For instance, they all run on data, and their rise has led to concerns about privacy rights and data security. In some cases, they are progressing in tandem. Genomic medicine is generating vast amounts of DNA data and practitioners are using AI to analyse it. AI also powers biometric facial and iris recognition.

These are not the only developments that are relevant to governments, of course. Virtual reality headsets embed a user's brain in an immersive 3D world. Surgeons could use them to practise risky surgeries on human-like patients, while universities are already using them to design enhanced classes for students. 3D printing produces components one layer at a time, allowing for more intricate design, as well as reducing waste. Governments are starting to use the technology to "print" public infrastructure, such as a new footbridge in Amsterdam, designed by the Dutch company MX3D.

Nanotechnology describes the manipulation of individual atoms and molecules on a tiny scale – one nanometer is a billionth of a metre. Nanoscale drug delivery could target cancer cells with new levels of accuracy, signalling a major advance in healthcare quality. Brain-mapping programmes like the US government-funded BRAIN initiative could allow mankind to finally understand the inner workings of the human brain and usher in revolutionary treatments for conditions such as Alzheimer's disease and depression.

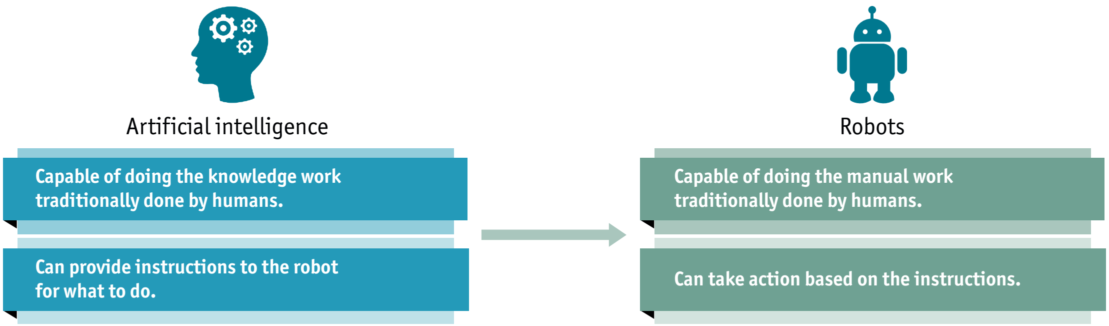
However, robots and AI, genomic medicine, and biometrics share three characteristics which mark them out as especially critical for governments. First, all three offer a clear way to improve, and in some cases revolutionise, how governments deliver their services, as well as improving overall government performance and efficiency. The three developments have also been trialled, to a certain extent, and so there is growing evidence on their effectiveness and how they can be best implemented. Finally, they are among the most transformative developments in terms of the degree to which they could change the way people live and work.

1. Robots and AI – Their long-heralded arrival is finally here

Robots and artificial intelligence (AI) can automate and enhance work traditionally done by humans. Often they operate together, with AI providing the robot with instructions for what to do. Google's driverless cars are a much-cited example.

The subject is of critical importance for governments. Robots are moving beyond their traditional roles in logistics and manufacturing and AI is already far more advanced than many people realise – powering everything from Apple's personal assistant, Siri, to IBM's Watson platform. Much of today's AI is based on a branch of computer science known as machine learning, where algorithms teach themselves how to do tasks by analysing vast amounts of data. It has been boosted by rapid expansions in computer processing power; a deluge of new data; and the rise of open-source software. Today, AI algorithms are answering legal questions, creating recipes, and even automating the writing of some news articles.

Robots and artificial intelligence – A combined approach

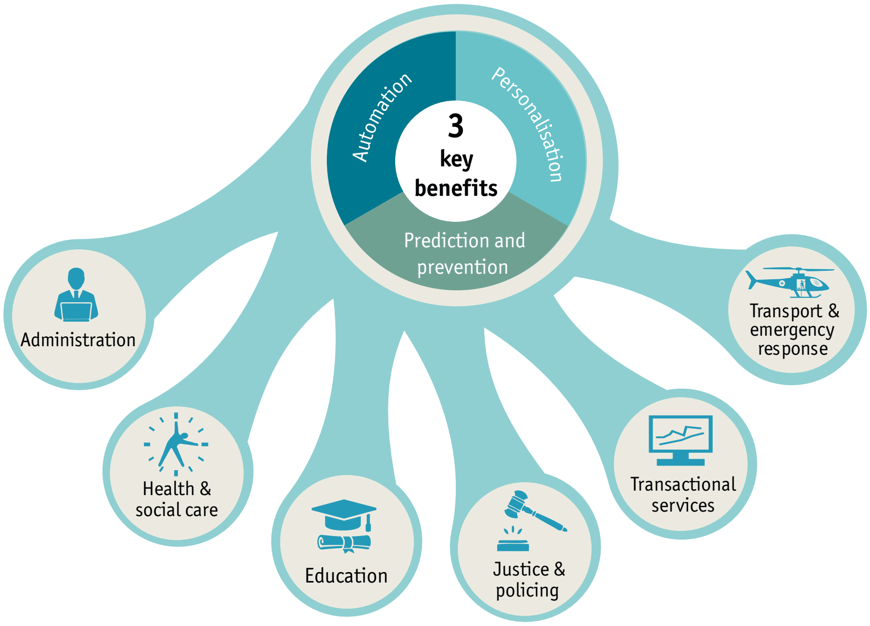


Source: EIU

Robots and AI have the potential to greatly enhance the work of governments and the public sector, by supporting automation, personalisation, and prediction. Automated exam grading can free up human teachers to focus on teaching, while automated robot dispensaries have reduced error rates in pharmacies. Governments can emulate Netflix, an online video service, by using AI to personalise the transactional services they provide to citizens. Crime-prediction algorithms are allowing police to intervene before a crime takes place.

Some worry about a future era of "superintelligence", led by advanced machines that are beyond the comprehension of humans. Others worry, with good reason, about the nearer-term effects on jobs and security. As a result, governments need to strike the right balance between supporting the rise of robots and AI, and managing their negative side effects.

How will robots and AI benefit governments?

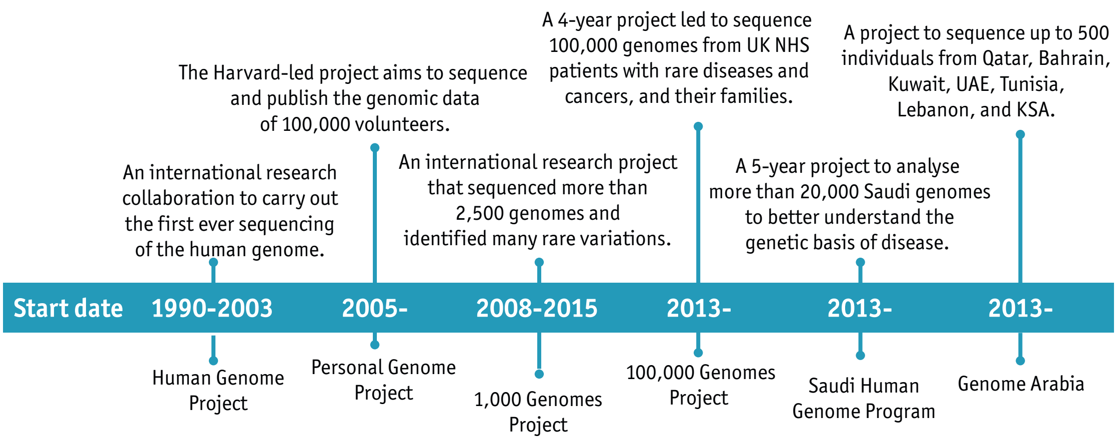


Source: EIU

2. Genomic medicine – Ushering in a new era of personalisation

Genomic medicine uses an individual's genome – ie, their unique set of genes and DNA – to personalise their healthcare treatment. Genomic medicine's advance has been boosted by two major developments. First, new technology has made it possible, and affordable, for anybody to quickly map their own genome. Second, new gene-editing tools allow practitioners to "find and replace" the mutations within genes that give rise to disorders.

Initiatives for sequencing genomes around the world

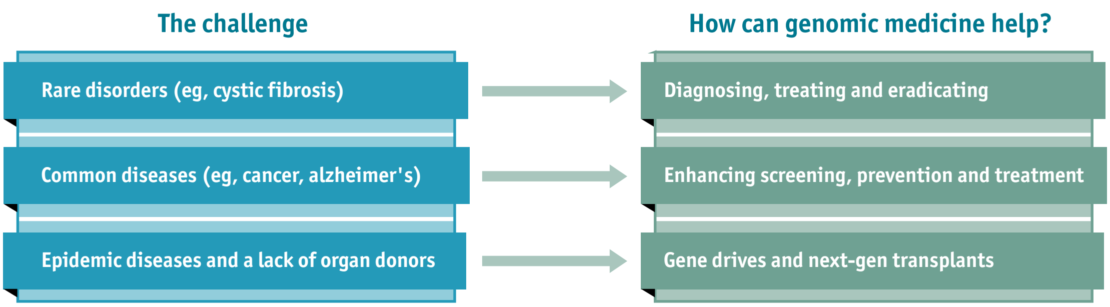


Source: EIU

Much of genomic medicine is relatively straightforward. Rare disorders caused by mutations in single genes are already being treated through gene editing. In time, these disorders may be eradicated altogether. For common diseases, such as cancer, patients' genomic data could lead to more sophisticated preventative measures, better detection, and personalised treatments.

Other potential applications of genomic medicine are mind-boggling. For instance, researchers are exploring whether gene editing could make animal organs suitable for human transplant, and whether "gene drives" in mosquito populations could help to eradicate malaria. The fast pace of development has given rise to ethical concerns. Some worry that prospective parents may try to edit desirable traits into their embryos' genes, to try to increase their baby's attractiveness or intelligence, for example. This, critics argue, is the fast route back to eugenics and governments need to respond appropriately.

How will genomic medicine affect healthcare?



Source: EIU

3. Biometrics – Mapping citizens, improving services

A biometric is a unique physical and behavioural trait, like a fingerprint, iris, or signature. Unique to every person, and collectable through scanning technologies, biometrics provides every person with a unique identification which can be used for everything from authorising mobile phone bank payments to quickly locating medical records after an accident or during an emergency.

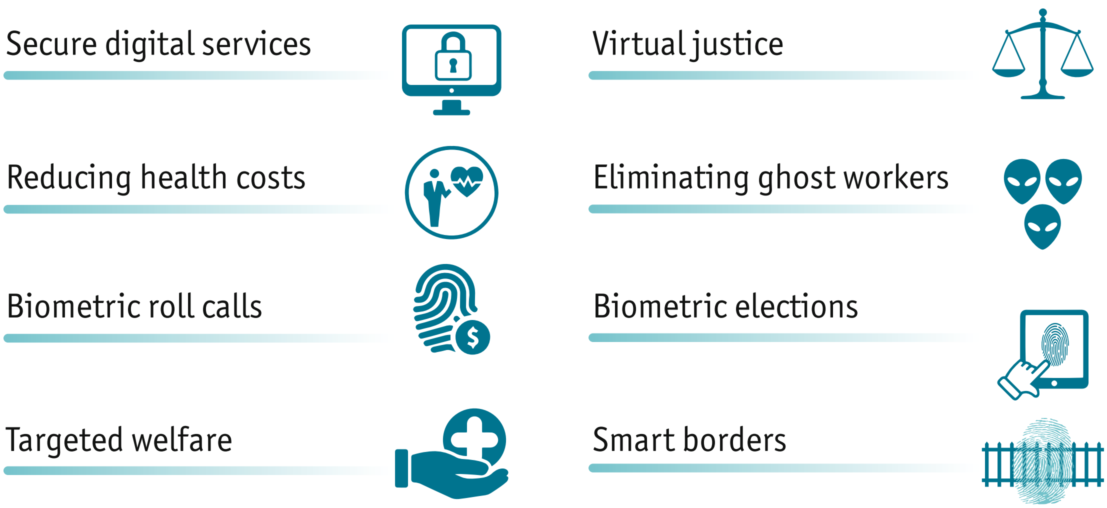
Humans have used biometrics for hundreds of years, with some records suggesting fingerprint-based identification as far back as the Babylonian era of 500 B.C. But its true scale is only now being realised, thanks to rapid developments in technology and the growing need for a more secure and efficient way of identifying individuals.

From a landmark national identification initiative in India to border control initiatives in Singapore, the US and the Netherlands, biometrics can be used in a wide range of government services. It is improving the targeting of welfare payments; helping to cut absenteeism among government workers; and improving national security. However, its use raises ethical challenges that governments need to manage – privacy issues, the risk of "mission creep", data security, public trust, and the financial sustainability of new technology systems. How can governments both utilise the benefits of biometric tools and manage the risks?

What is biometrics?

Source: EIU

How is biometrics being used by governments?



Source: EIU

How does this report help policymakers?

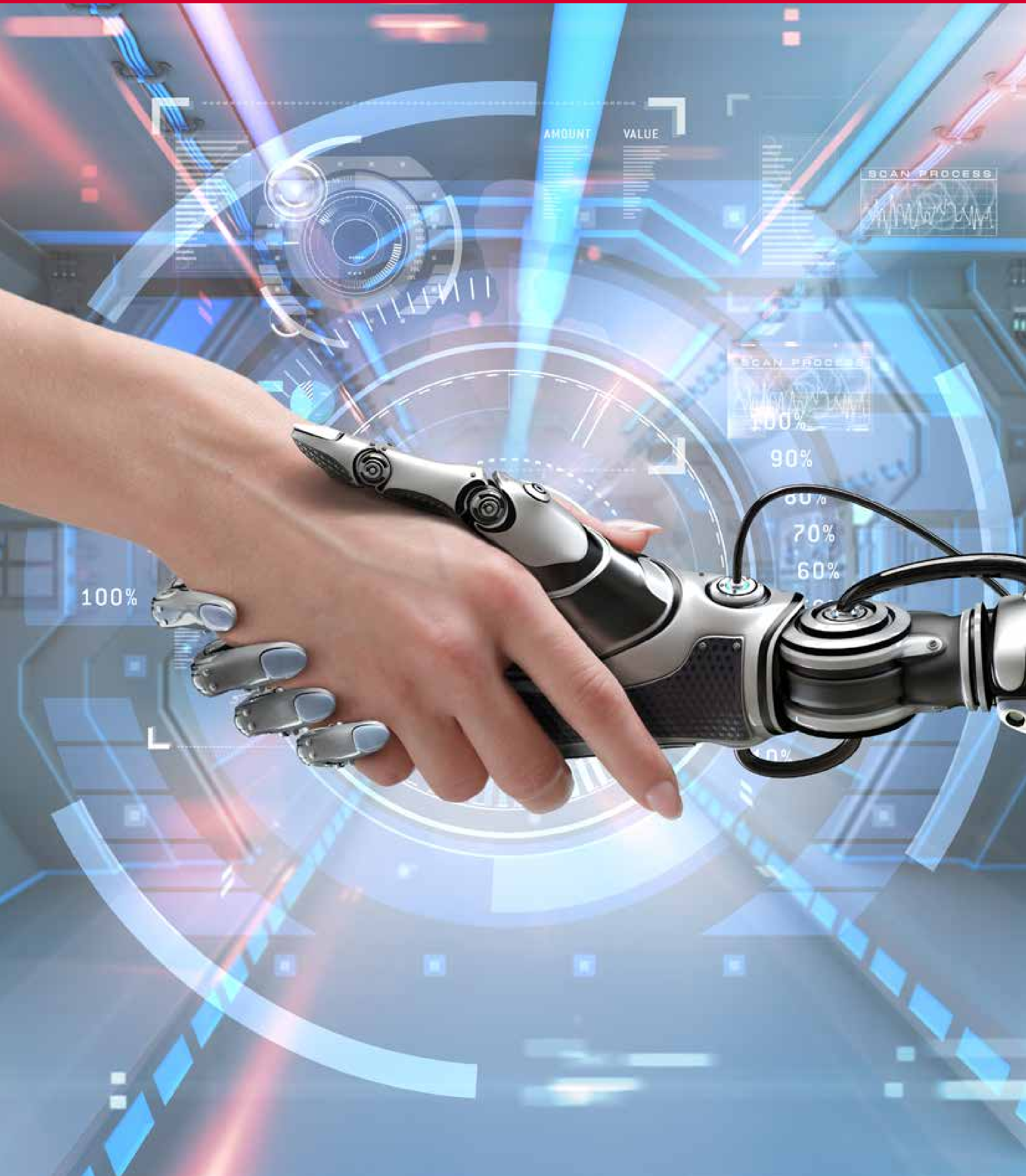
This report is designed to help policymakers in three ways. First, robots and AI, genomic medicine, and biometrics are technical topics and it can be difficult for non-experts to understand exactly what they are. What's more, they are often poorly explained in the media articles that report on them. This can lead to misunderstandings, particularly when it comes to the risk of imminent negative consequences. This report aims to address this, by providing a clear and concise overview of what each of the advances entails, as well as summarising how they have developed to date.

Second, discussions about the impact of robots, AI, genomic medicine and biometrics often focus on their use in the private sector. However, advances in all three fields could transform how governments deliver services, as well as enhancing government productivity and efficiency. This report describes these potential impacts on governments' work, citing examples from around the world.

Finally, advances in all three areas require a response from governments. In some cases, new legislation and policies will be needed. For instance, new guidelines are required for storing biometric data for law-enforcement purposes to guard against the possible targeting of ethnic minorities. Companies must be forbidden from using citizens' genomic data to discriminate against them. Robots and AI will cause some jobs to disappear and so policies such as guaranteed incomes will need consideration.

In other cases, governments will need to support the advances by unblocking bottlenecks. For instance, universities and hospitals will need to design new courses for students and staff on how to use, store, and analyse patients' genomic data. In certain situations, particularly those involving ethical issues, the optimal response is unclear and is likely to differ across countries. For instance, how does AI interpreting data from surveillance cameras affect "traditional" privacy rights? Should the government support research into the genetic basis of intelligence? This report provides guidance to government leaders, who must answer these tough questions in the years ahead.

Chapter 1: Robots and Artificial Intelligence



Executive Summary

Robots and Artificial intelligence (AI) can automate and enhance the work that is traditionally done by humans. Often they operate together, with AI providing the robot with instructions for what to do. Google's driverless cars are a prominent example.

The subject is of critical importance. Robots are moving beyond their traditional roles in logistics and manufacturing. AI is already far more advanced than many people realise – powering everything from Apple's personal assistant, Siri, to IBM's Watson platform. Much of today's AI is based on a field of computer science known as machine learning, where algorithms teach themselves how to do tasks by analysing vast amounts of data. It has been boosted by rapid expansions in computer processing power; a deluge of new data; and the rise of open-source software. Today, AI algorithms are answering legal questions, creating recipes, and even automating the writing of some news articles.

Some worry about a new era of "superintelligence", led by advanced machines that are beyond the comprehension of humans. Others worry about the near-term effects on jobs and security. Critically, however, robots and AI also have the potential to greatly enhance government work. Automated exam grading can free up human teachers to focus on teaching, while automated robot dispensaries have reduced error rates in pharmacies. Governments can emulate Netflix, an online-video service, by using AI to offer personalised transactional services. Crime-prediction algorithms are allowing police to intervene before a crime take place.

This chapter starts with an overview of what exactly robots and AI are, before explaining why they are now experiencing rapid uptake, when they haven't in the past. It then assesses how robots and AI can improve the work of governments in areas as diverse as education, justice, and urban planning. The chapter concludes with suggestions for government leaders on how to respond.

Background

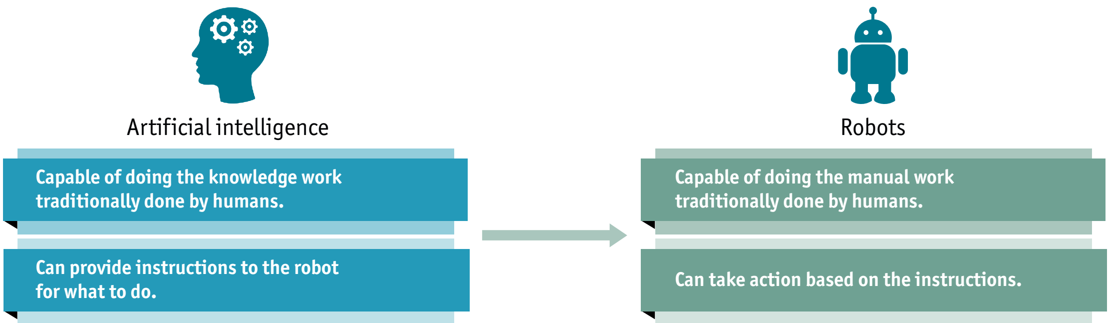
Jeopardy! is a long-running American quiz show with a famous twist. Instead of the presenter asking contestants questions, he provides them with answers. The contestants must then guess the correct question. In 2011, a first-time contestant called Watson shocked viewers when it beat *Jeopardy!*'s two greatest-ever champions – who between them had won more than US$5m. Although it sounded human, Watson was actually a machine created by IBM and powered by AI.

Some dismissed the achievement as trivial. After all, computers have been beating humans at chess for years. However, winning *Jeopardy!* was a far bigger achievement. It required Watson to understand tricky colloquial language (including puns), draw on vast pools of data, reason as to the best response, and then annunciate this clearly at the right time. Although it was only a TV quiz show, Watson's victory offered a vision of the future, where robots and AI potentially carry out a growing portion of the work traditionally done by humans.

Robots and AI: What are they?

Defining robots and AI is difficult since they cover a vast spectrum of technologies – from the machines zooming around Amazon's warehouses to the automated algorithms that account for an estimated 70% of trades on the US stock market.[1] One approach is to think in terms of capabilities. Robots are machines that are capable of automating and enhancing the *manual* work done by humans. AI is software that is capable of automating and enhancing the *knowledge-based* work done by humans. Often they operate together, with AI providing the robot with instructions for what to do. Robots and AI do not simply mimic what humans do – they can draw on their own strengths. In some cases, this allows them to do things that no human, no matter how smart or physically powerful, could ever do.

Robots and artificial intelligence – A combined approach



Source: EIU

Robots – New shapes, new sizes; More automated, more capable

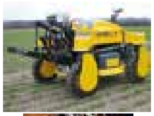
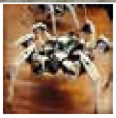
The term "robot" is derived from a Slavic word meaning "monotonous" or "forced labour", and gained popularity through the work of science fiction authors such as Isaac Asimov. In the 1950s, the Massachusetts Institute of Technology (MIT) demonstrated the first robotic arm and in 1961, General Motors installed a 4,000 lb version in its factory and tasked it with stacking die-cast metal. Over time, the use of robots in logistics and manufacturing grew. However, their long-heralded entrance into other sectors, such as fast food and healthcare, is yet to be realised. This looks set to change.

When people think about robots, they typically think about *humanoids* – ie, those that look and act like humans. In June 2015, South Korea's DRC-HUBO humanoid won the annual DARPA Robotics Challenge after demonstrating an impressive ability to switch between walking and "wheeling". However, humanoids remain limited. They are prone to falling over and have trouble dealing with uncertain terrain. The logic behind developing them is also questionable. While humans can carry out an impressive range of tasks, we are not necessarily well suited to many of them – our arms are too weak, our fingers are too slow, and most of us are too big to get into tight spaces. Building robots to emulate humans might thus be a self-limiting approach.

A separate breed of robot is more promising. These look nothing like humans. Instead, they are designed entirely with their environment in mind and come in many shapes and sizes. Kiva robots (since renamed as Amazon robotics) look like large ice hockey pucks. They glide under boxes of goods and transfer them across Amazon's warehouses. They bear little resemblance to the Prime Air drone robots that Amazon wants to use to deliver packages; or to the Da Vinci, the world's most popular surgical robot, which looks like a set of octopus arms. While they look different, this breed of robot shares a common goal: mastering a narrow band of tasks by using the latest advancements in robotic movement and dexterity.

These robots also differ in their degree of automation. Amazon's Kiva robots operate largely independently, and few humans are visible in the next-generation warehouses where they operate – Amazon's management forecasts that their use will lead to a 20-40% reduction in operating costs.[2] By contrast, the Da Vinci remains directly under the control of human surgeons – essentially providing them with extended "superarms" with capabilities and precision far beyond their own.

Modern-day robots in action

Types		What are they and what do they do?
Amazon robots		The robots move around Amazon warehouses independently, collecting goods and bringing them to human packagers for dispatch.
Da Vinci		Miniaturised surgical instruments are mounted on three robotic arms, while a fourth arm contains a 3D camera that places a surgeon "inside" the patient's body.
Sawyer		A robot produced by Rethink Robotics that is used in factories to tend to machines and to test circuit boards. Works alongside humans.
Paro		Developed by a Japanese firm called AIST to interact with patients suffering from Alzheimer's, and other cognition disorders.
Agrobot		A robot developed by a Spanish entrepreneur that automates the process of picking fruits.
Spiderbot		A robot created by Intel that is made up 3D-printed components. Can be controlled via a smartphone or smartwatch.

Source: EIU

Artificial intelligence – Finally living up to its potential?

Today most people come across AI on a daily basis. It powers everything from Google Translate, to Netflix's movie recommendations, to Apple's personal adviser, Siri. However, much of this

AI powers everything from Google Translate, to Netflix's movie recommendations, to Apple's personal advisor, Siri.

AI is "invisible" and takes place behind a computer screen, so many users have little idea that it is happening.

The field of AI emerged in the 1950s when Alan Turing, a pioneering British codebreaker during the second world war, published a landmark study in which he speculated about the possibility of creating machines that could think.[3] In 1956, the Dartmouth Conference in the US asked leading scientists to debate whether human intelligence could be "so precisely described that a machine can be made to simulate it".[4] At the conference, the nascent field was christened "artificial intelligence", and wider interest (and investment) began to grow.

However, the subsequent half-century brought crushing disappointment. In many cases there was simply not enough data or processing power to bring scientists' models, and the nuances of human intelligence, to life. Today, however, many experts believe that we are entering a golden era for AI. Firms like Google, Facebook, Amazon and Baidu agree and have started an AI arms race: poaching researchers, setting up laboratories, and buying start-ups.

> Playing chess is easy for a computer but difficult for a human. When it comes to understanding what a person is saying, the opposite is true.

To understand what AI is and why it is now developing, it is necessary to understand the nature of the human intelligence that it is trying to replicate. For instance, solving a complex mathematical equation is difficult for most humans. To do so, we must learn a set of rules and then apply them correctly. However, programming a computer to do this is easy. This is one reason why computers long ago eclipsed humans at "programmatic" games like chess which are based on applying rules to different scenarios.

On the other hand, many of the tasks that humans find easy, such as identifying whether a picture is showing a cat or a dog, or understanding what someone is saying, are extremely difficult for computers because there are no clear rules to follow. AI is now showing how this can be done, and much of it is based on a field of computer science known as machine learning.

Machine learning – The algorithms that power AI

Machine learning is a way for computer programs (or algorithms) to teach themselves how to do tasks. They do so by examining large amounts of data, noting patterns, and then assessing new data against what they have learned. Unlike traditional computer programs, they don't need to be fed with explicit rules or instructions. Instead, they just need a lot of useful data.

Consider the challenge of looking at a strawberry and assessing whether it is ripe. How can a machine-learning algorithm do this? First, large sets of "training data" are needed – that is, lots of pictures of strawberries. If each strawberry is labelled according to its level of ripeness, the algorithm can draw statistical correlations between each strawberry's characteristics, such as nuances in size and colour, and its level of ripeness. The algorithm can then be unleashed on new pictures of strawberries and can use what it has learned to recognise those that are ripe.

To perform this recognition, machine learning can use models known as artificial neural networks (ANNs). These are inspired by the human brain's network of more than 100 billion neurons –

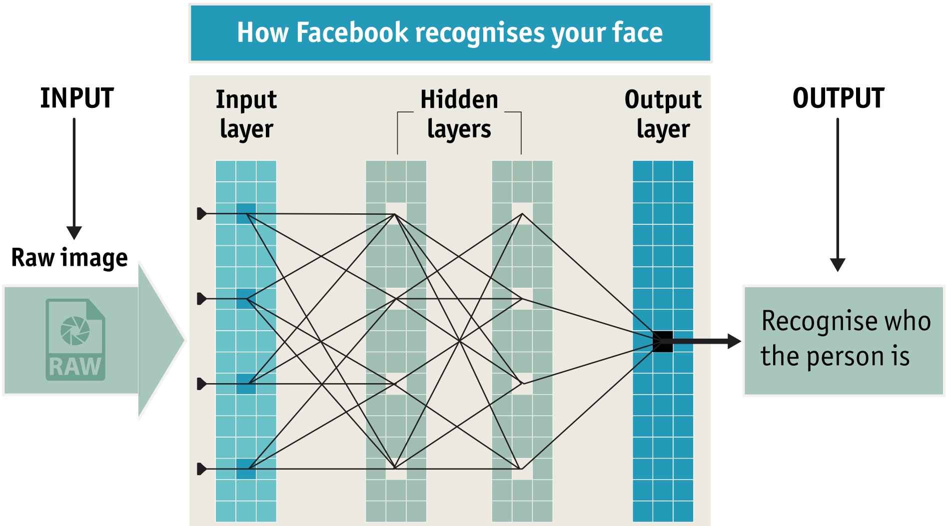
interlinked cells that pass signals or messages between themselves, allowing humans to think and carry out everyday tasks. In a (somewhat crude) imitation of the brain, ANNs are built on hierarchical layers of transistors that imitate neurons, giving rise to the term "deep learning".

When it is shown a new picture of a strawberry, each layer of the ANN deals with a different approximation of the picture. The first layer may recognise the brightness and colours of individual pixels. It passes these observations to the next layer, which builds on them by recognising edges, shadows and shapes. The next layer builds on this again, before finally recognising that the image is showing a strawberry and assessing whether it is ripe or not.

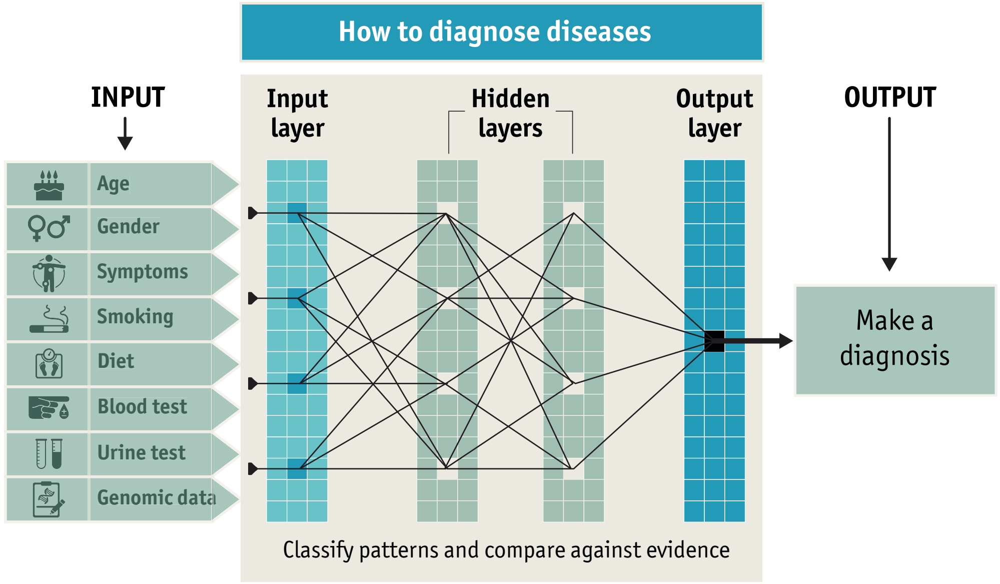
What can machine-learning algorithms do? A surprising amount

Facebook's AI laboratory has developed a machine-learning algorithm called Deep Face that recognises human faces with a 97% accuracy rate. It does so by studying a person's existing Facebook pictures and identifying their unique facial characteristics (such as the distance between their eyes). When a new picture is uploaded to Facebook, the algorithm automatically recognises the people in it and invites you to tag them.

How neural networks work



A neural network is organised into layers. Information from individual pixels causes neurons in the first layer to pass signals to the second, which then passes its analysis to the third. Each layer deals with increasingly abstract concepts, such as edges, shadows and shapes, until the output layer attempts to categorise the entire image.



Sources: The Economist, EIU

The data that power algorithms do not need to be images. Algorithms can also make sense of articles, video recordings, or even messy, "unstructured" data such as handwritten notes. Once an algorithm has learned something, it can take an action, such as producing a written report explaining the logic of its prediction, or sending instructions to a robot for which pieces of fruit to pick.

Taken as a whole, machine-learning algorithms can do many things – primarily tasks that are routine, or can be "learned" by analysing historical data. Talk into your phone and a Google app can instantly translate it into a foreign language. The results are imperfect, but improving, as algorithms draw on ever-larger "translation memory" databases to understand what words mean in different contexts. Netflix uses machine learning to "personalise" the homepage and movie recommendations that users see. Algorithms infer a user's preferences based on their past interactions on the site (such as watching, scrolling, pausing, and ranking); the interactions of similar users; and contextual factors (time of day, device, location, etc.). They then predict the content that will be most receptive to the user.

More surprisingly, machine learning is being applied to fields like writing and music composition. While most people would not consider these to be "routine", they are also based on data patterns which can be learned and applied.

Machine learning in action

Writing	Quill is a platform that automates the writing of financial reports and sports articles for outlets like Forbes.
Creating recipes	IBM's Watson analysed the Bon Appétit recipe database to recognise tasty food pairings and created an app to suggest recipes based on the ingredients that a person has available.
Financial advice	Wealthfront is an AI-powered financial advisor that assess a person's characteristics (such as age and wealth), their objectives, and then uses investing techniques to suggest what assets to invest in.
Music composition	Iamus is an algorithm that is fed with specific information, such as which instruments should be used and what the desired duration should be. It then creates its own orchestral compositions from scratch.
Video games	DeepMind developed a "general learning" algorithm that exceeded all human players in popular video games, from Space Invaders to car racing games. It was purchased by Google in 2014.

Source: EIU

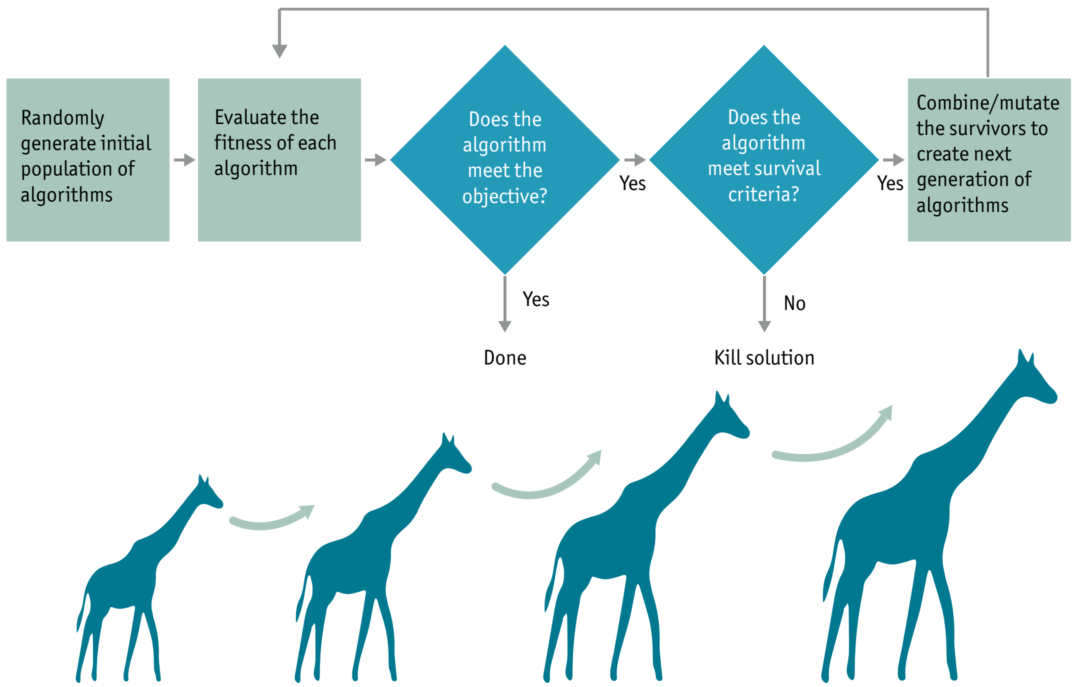
Not just learning, but teaching itself and improving

Much of machine learning involves making predictions based on probability, but on a scale that a human brain could never achieve. An algorithm does not "know" that a strawberry is ripe in the same way that a human brain does. Rather, it predicts whether it is ripe according to its evaluation of data and comparing this with past evidence.

Having labels for the training data (such as "ripe" and "rotten" for pictures of strawberries) makes things easier for the algorithm, but is not a prerequisite. "Unsupervised algorithms" take vast amounts of data that make little sense to a human. If they see enough repeated patterns they will make their own classifications. For instance, an algorithm may analyse massive sets of genomic data belonging to thousands of people and discover that certain gene mutations are associated with certain diseases (see chapter 2). In this scenario, the algorithm is teaching itself.

Practitioners do not need to spend lifetimes crafting hugely complex algorithms. Rather, "genetic algorithms" are often used. As their name implies, they use trial-and-error to mimic the way natural selection works in the living world. With each run of the program, the highest-scoring algorithms are retained as "parents". These are then "bred" to create the next generation of algorithm. Those that don't work are discarded. Once they are in use, algorithms can improve themselves by analysing the accuracy of their predictions and making tweaks accordingly (known as "reinforcement learning").

Survival of the fittest – How natural selection is applied to algorithms



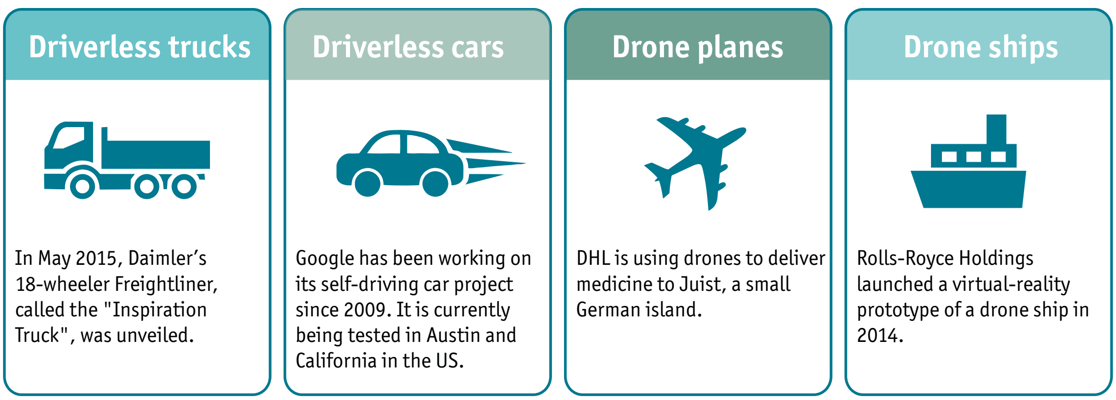
Source: EIU

Robots and AI – Merged in symphony

Driverless cars (and other automated vehicles) are perhaps the best example of how robots and AI can come together to awesome effect. The global positioning system (GPS) provides the robot (ie, the car) with a huge set of mapping data, while a set of radars, sensors, and cameras provide data on what is happening around it. Machine-learning algorithms evaluate all of this data and, based on what they have previously learned, issue real-time instructions for steering, braking, and accelerating.

Driverless cars are perhaps the best example of how robots and AI can come together to awesome effect.

The new era of driverless vehicles



Source: EIU

Other examples abound. Unlike harvesting corn, fruit picking still relies heavily on human hands. A Spanish firm called Agrobot promises a robotic alternative. Its robot harvester is equipped with 14 arms for picking strawberries. Each arm has a camera that takes 20 pictures per second. Algorithms analyse these images and assess the strawberries' colour and shape against the desired level of "ripeness". If a strawberry is judged to be ripe, the robot's arm positions its basket underneath it, and a blade snips the stem. The whole process takes four seconds. Some human labour is needed to supervise the robot, but much less than what is required to pick strawberries manually. The robot can work night and day, and a new version, with 60 arms, is being trialled.[5]

The rise of robots and AI – Why now, and how far can it go?

The standard joke about robots and AI is that, like nuclear fusion, they have been the future for more than half a century. Many techniques, like neural networks, date back to the 1950s. So why is today any different? The main reason is that the underlying infrastructure powering robots and AI has changed dramatically.

First, the processing power of computer chips has grown exponentially. People are often vaguely familiar with Moore's law – ie, the doubling every year of the number of transistors that can be put on a microchip. However, its impact is rarely fully appreciated. The designers of the first artificial neural networks in the 1960s had to rely on models with hundreds of transistor neurons. Today, those built by Google and Facebook contain millions. This allows AI programs to operate at a speed that is hard for a human to comprehend.

Second, AI systems run on data, and we live in a world that is deluged – from social media posts, to the sensors that are now added to an array of machines and devices, to the vast archives of digitised reports, laws, and books. In the past, even if such data were available, storing and accessing it would have been cumbersome. Today, cloud computing means that much of it can be accessed from a laptop. In 2011, IBM's Watson was the size of a room. Now it is spread across servers in the cloud and can serve customers across the world.

Finally, robots and AI are increasingly accessible to the world, rather than just to scientists. DIY robot kits are much cheaper than industrial robots, and companies like EZ Robot even allow customers to "print" robot components using 3D printers. In August 2015, Intel presented its "spiderbot" – a spider-like robot constructed from 9,000 printed parts. A growing number of machine-learning algorithms are free and open-source, as is the software on which many robots run (Robot Operating System). This allows developers to quickly build on each other's work. IBM has also made Watson available to developers, with the aim of unleashing a new ecosystem of Watson-powered apps – like those found in Apple's iTunes store.

How far can robots and AI develop?

Robots and AI already offer the potential to automate, and possess five key human capabilities: movement, dexterity, sensing, reasoning and acting.

How robots and AI emulate human capabilities

	MOVEMENT	DEXTERITY
Human capabilities	Being able to get from place to place.	Using one's hands to carry out various tasks.
How robots do it	Robots move in many ways. Hexapods walk on six legs like an insect. Snakebots slither and can change the shape of their body. Wheelbots roll on wheels.	Today's robots boast impressive dexterity. They can fold laundry, remove a nail from a piece of wood, and screw a cap on a bottle.

	SENSING	REASONING	ACTING
Human capabilities	Taking in data about the world, or about a problem.	Thinking about what a new set of data means.	Acting on what you have discovered.
How AI does it	Computer vision can understand moving images, chemical sensors can recognise smells, sonar sensors can recognise sounds, and taste sensors can recognise flavours.	Machine learning analyses data to identify patterns or relationships. It can be used to "understand" speech, images, and natural language. It can assess new data against past evidence and make predictions or recommendations.	Natural language and speech generation can be used to document findings. Findings can also be given to a robot, as instructions for how to act.

Source: EIU

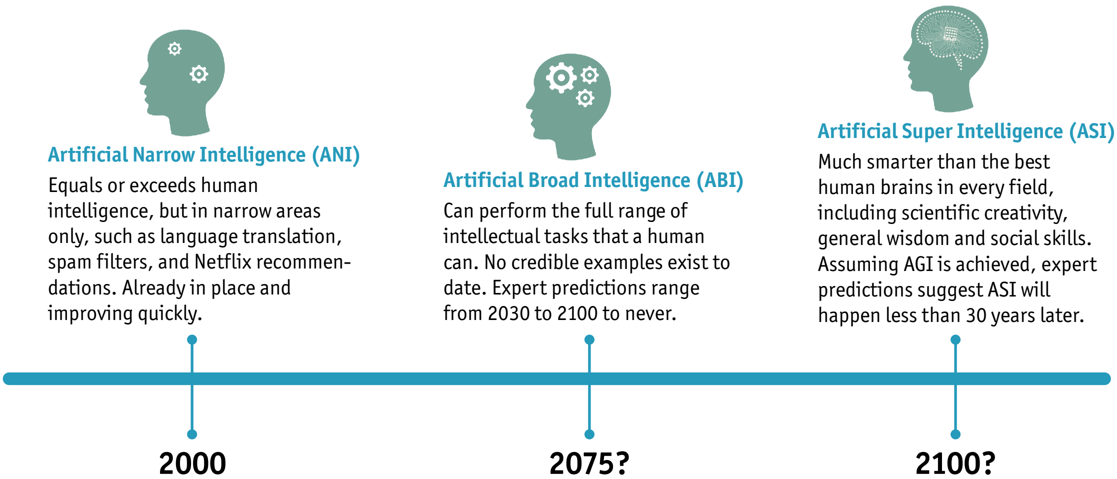
How far can they expand beyond this? A famous test developed by Alan Turing is the "imitation game". In it, an individual converses with two entities in separate rooms: one is a human and one is an AI-powered machine. If the individual is unable to identify which is which, the machine wins. Every year, the Loebner Prize is offered to any AI program that can successfully trick a panel of human experts in this way. To date, none has come close – although other competitions, with shorter test times, have claimed (much disputed) victories.

The goal of the Turing test is to achieve what is known as "broad AI" – ie, AI that can do *all* of the things that the human brain can do, rather than just one or two narrow tasks. There are huge debates among scientists about whether broad AI will be achievable and, if so, when. One challenge is that much of how the human brain works remains a mystery, although projects such as the BRAIN Initiative in the US and the Blue Brain Project in Switzerland, which aim to build biologically detailed digital reconstructions of the human brain, aim to address this.

A survey of leading scientists carried out by philosopher Nick Bostrom in 2013 found that most believed that there was a 50% chance of developing broad AI by 2040-50, and a 90% chance by 2075.[6] If broad AI is achieved, some believe that it would then continue to self-improve, ushering in an era of "super intelligence" and a phenomenon known as the "technological singularity" (see below).

Source: EIU

Narrow AI v broad AI v super AI



Source: EIU

Case study: What is the technological singularity?

If AI can reach a level where it matches the full breadth of human intelligence, some futurists argue that its ability to self-improve, backed by ever-increasing computing power, will lead to an "intelligence explosion" and the rise of "super intelligence". In such a scenario, machines would design ever-smarter machines, all of which would be beyond the understanding, or control, of even the smartest human. The resulting situation – the technological singularity – would be unpredictable and unfathomable to human intelligence. Some dream of a new utopia, while others worry that super-intelligent machines may not have humanity's best interests at heart.

The technological singularity's most famous proponent is Ray Kurzweil, who predicts that it will occur around 2045. Kurzweil argues that humans will merge with the machines of the future, for instance through brain implants, in order to keep pace. Some "singularians" argue that super-intelligent machines will tap into enhancements in genomics and nanotechnology to carry out mind-boggling activities. For instance, "nanobots" – robots that work at the level of atoms or molecules – could create any physical object (such as a car or food) in an instant. Immortality could be achieved through new artificial organs or by uploading your mind into a robot.[7]

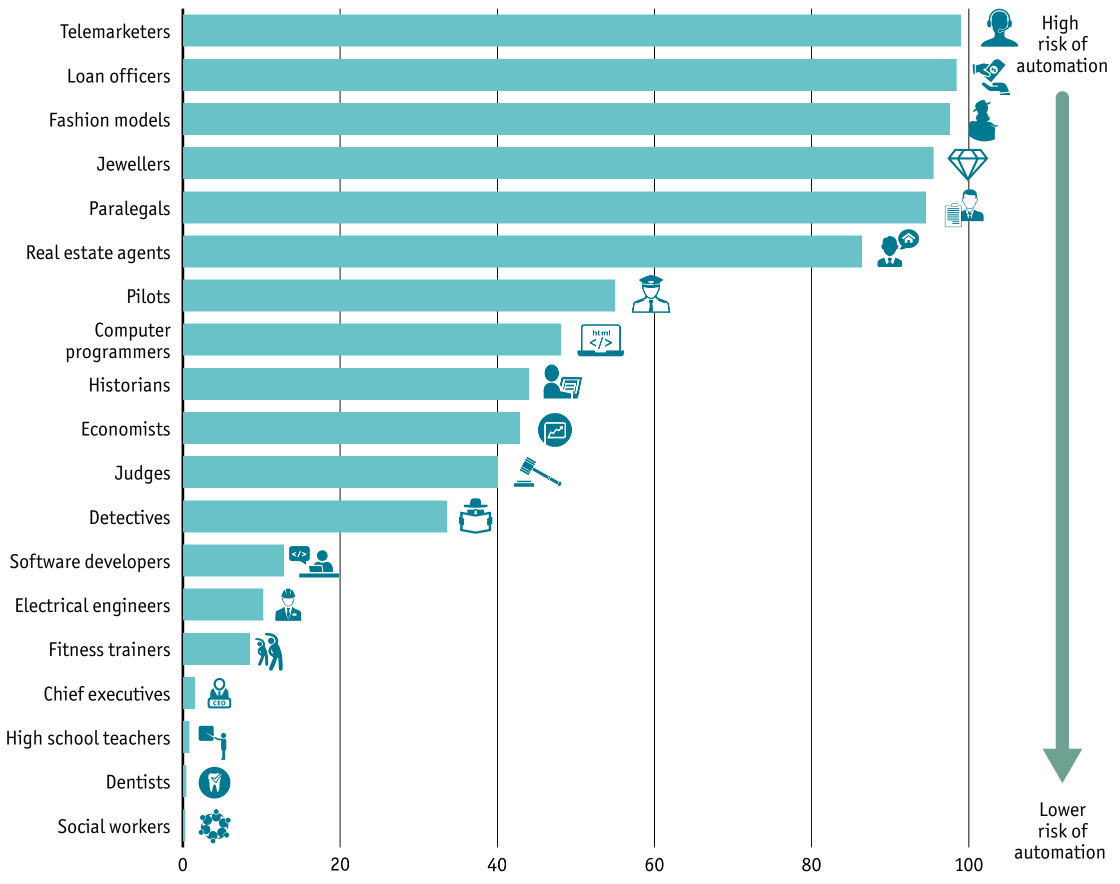
Perhaps not surprisingly, the technological singularity has been dismissed by critics and likened to a religious cult.[8] However, it continues to be debated, largely because of the achievements of those advocating it. A serial inventor and futurist, Kurzweil made 147 predictions in 1990 of what would happen before 2009. These ranged from the digitisation of music, movies, and books to the integration of computers into eyeglasses. 86% of the predictions later proved to be correct.[9] In 2012 he was hired by Google as its head of engineering. He also launched the Singularity University in Silicon Valley, which is sponsored by Google and Cisco, among others.

Discussions about the technological singularity generate both fascination and derision. It would be unwise to dismiss it completely. While the human brain is complex, there is nothing supernatural about it – and this implies that building something similar inside a machine could, in principle, be possible. However, it is crucial to note that the vast majority of today's AI work does not aspire to be "broad" or "super". Rather it is "narrow" and fully focused on mastering individual tasks – especially those that are repetitive or based on patterns. Despite this apparent limitation, even narrow AI covers considerable ground.

How will robots and AI affect government?

There is much concern in policy circles about robots and AI. First there is the fear that they will destroy jobs. Such worries were fuelled in 2013 when a study by academics at Oxford University predicted that 47% of jobs were at risk of replacement by 2030.[10] Notably, many "safe" middle-class professions, requiring considerable training, such as radiographers, accountants, judges, and pilots, appear to be at risk. Other jobs appear less at risk – for the moment – particularly those which are highly creative, unpredictable, or involve dealing with children, people who are ill, or people with special needs.

Jobs at risk of automation from robots and AI

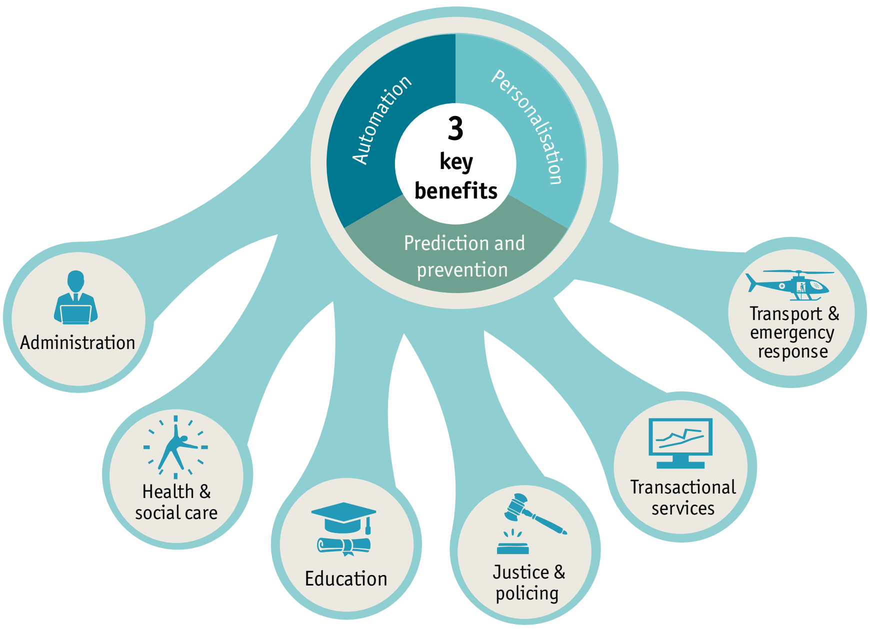


Sources: Oxford University, EIU

The second fear concerns security threats. These gained traction in January 2015, when a group of prominent thinkers, including Stephen Hawking and Elon Musk, signed an open letter calling for responsible oversight of AI to ensure that research focuses on "societal benefit", rather than simply enhancing capabilities.[11] Of particular concern is the risk posed by lethal autonomous weapons systems (LAWS). LAWS are different from the remotely piloted drones that are already used in warfare: drones' targeting decisions are made by humans, whereas LAWS can select and engage targets without any human intervention. According to computer science professor Stuart Russell, they could include armed quadcopters that can seek and eliminate enemy combatants in a city.[12] Often described as the third revolution in warfare, after gunpowder and nuclear arms, the first generation of LAWS are believed by experts interviewed by the Economist Intelligence Unit to being close to complete. The remaining barriers are legal, ethical, and political, rather than technical.

Fears about jobs and security are worthy of government attention. Crucially, however, robots and AI also have the potential to greatly enhance the work of government. These improvements are possible today and some government agencies have already started trials. The benefits will come in three main forms and, in theory, could apply to almost all areas of a government's work.

How will robots and AI benefit governments?



Source: EIU

Automation: Robots and AI can automate and enhance some government work. Such automation will not necessarily spell the end for the employee in question. Rather, it could free up their time to do more valuable and interesting tasks. It could also eliminate the need for humans to undertake dangerous work such as defusing bombs.

Personalisation: In the same way that AI powers Netflix recommendations for subscribers, it could also power a new generation of personalised government services and interactions – from personalised treatment plans for patients, to personalised learning programmes for students and personalised parole sentences for prisoners.

Prediction and prevention: One of AI's main uses is making predictions based on what it has learned. In certain situations, such predictions could allow governments to intervene and prevent problems from occurring. This could dramatically enhance how police services and courts work, as well as support the strategies of urban planners.

1. Education: Automated exam grading, adaptive learning platforms, and robot kits

Marking exams is repetitive and time-pressured – a combination that can allow mistakes to creep in. As most exams are graded on specific criteria, and past examples are available, it seems a sensible candidate for AI. In 2012, a study carried out by researchers at the University of Akron in Ohio tasked an AI-powered "e-rater" with assessing 22,000 English literature essays.[13] The grades awarded were strikingly similar to those given by human evaluators. The main difference was the speed of the activity - the e-rater was able assess 16,000 essays in 20 seconds. It can also provide explanations for its marking – including comments on grammar and syntax.

Unsurprisingly, the technology is not welcomed by all. In the US, the National Council of Teachers of English has campaigned against it, claiming that it misses subtlety and rewards writing that is geared solely towards test results (although this is arguably true of any criteria-based assessment). Critics have also demonstrated how the algorithms can be "tricked" into awarding high marks without actually writing a good essay. Despite the controversy, the role of e-raters looks set to grow – either as a check on teachers' grading, or working under teachers' supervision. Australia's Curriculum, Assessment and Reporting Authority (ACARA) recently announced that e-raters will mark the country's national assessment programme for literacy and numeracy by 2017.

Less controversial are personalised education (or "adaptive learning") programmes. As with healthcare, a great deal of today's education is delivered on a one-size-fits-all basis – with most students using the same textbooks and doing the same homework. Teachers often have little option but to "teach to the middle" – resulting in advanced students becoming bored and struggling students falling behind.[14] A company called Knewton has developed a platform that tracks students as they complete online classes in maths, biology, and English, and attempt multiple-choice questions. It assesses how each student performs and compares this with other students' past records. It then decides what problem or piece of content to show next. Pearson, the world's largest education company, has partnered with Knewton to deliver a similar service for college students called MyLab & Mastering, which is used by more than 11m students worldwide every year.[15]

As with most AI-led solutions, there is a degree of hype about such platforms, and their accuracy and usefulness will depend on scale – the more users they have, the more accurate they will become. However, several platforms have merits, particularly in subjects such as maths that require students to master theories through repeated examples. More experimental systems can recognise a student's emotional state (such as tiredness or boredom)

> Humanoid teachers are unlikely to enter classrooms in the near future, but robot teaching kits are increasingly common.

and provide motivational advice to help them persevere.

Given the complexity involved in interacting with children, *humanoid robotic teachers* are unlikely to take over classrooms in the near future. However, "robot kits", such as the Lego Mindstorms series, are increasingly used in science, technology, engineering and maths (STEM) classes. Students are given the kits and asked to construct a robot and program it to carry out tasks. Evidence suggests that they can provide a more effective way of teaching various maths and engineering concepts – such as equations.[16] In contrast to some traditional STEM teaching methods, they also help to build teamwork and problem-solving capabilities – key "21st-century skills" that schools are trying to nurture.[17]

2. Health & social care: Personalised treatment, robot porters, and tackling ageing

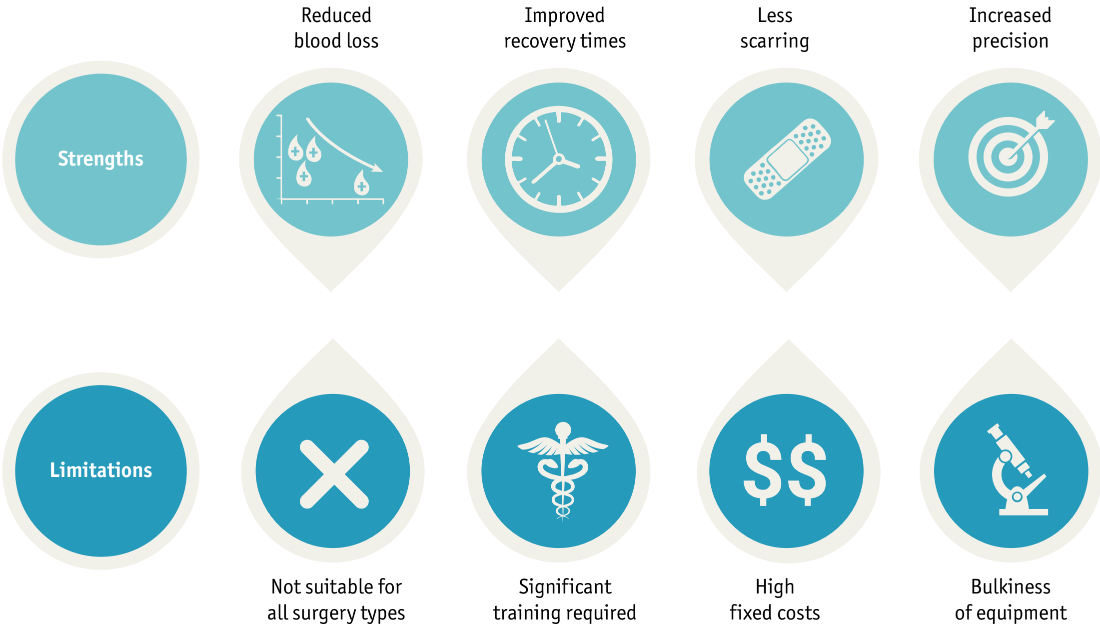
Much of the excitement around AI has focused on its potential use in healthcare. In 2015, @Point of Care, a firm based in New Jersey, trained IBM's Watson to answer thousands of questions from doctors and nurses on symptoms and treatments, based on the most up-to-date peer-reviewed research. In an interview with the Economist Intelligence Unit, Sir Malcolm Grant, chairman of NHS (National Health Service) England, claimed that the combination of AI and patients' genomic data could allow "clinicians to make more efficient use of expensive drugs, such as those used in chemotherapy, by attuning them to tumour DNA and then monitoring their effect through a course of treatment".

"The combination of AI and patients' genomic data could allow clinicians to make more efficient use of expensive drugs."
- Sir Malcolm Grant, chairman of NHS England.

While much of AI's potential in healthcare is still at the trial stage, robots are already present in hospitals. In 2015, the UK media reported excitedly about an NHS plan to introduce robot porters. The machines, which look similar to those found in Amazon's warehouses, will transport trolleys of food, linen and medical supplies. In pharmacies, robot prescription systems are increasingly common. At the University of California San Francisco Medical Center, a doctor produces an electronic prescription and passes it to a robot arm that moves along shelves picking out the medicine needed. The pills are sorted and dispensed into packets for patients. Under the system, the error rate has fallen from 2.8% to 0%.[18]

Surgical robots are used in a growing number of operations, including coronary bypasses, hip replacements, and gynaecological surgeries. In the US, they carry out the majority of prostate cancer operations (radical prostatectomies).[19] In certain operations, they offer greater precision and reduced scarring, and can reduce blood loss.[20] However, they are also expensive and must remain under the close control of trained surgeons at all times.

The pros and cons of surgical robots



Source: EIU

Robots have been touted as a way to address the global ageing phenomenon. Over the next 20 years, the number of people aged 65 and over will almost double to 1.1bn.[21] Diseases such as dementia are set to become more prevalent, while the labour force – whose taxes pay for treatments – will shrink. Dementia patients often suffer from a lack of social engagement, which can magnify feelings of loneliness, leading to depression and cognitive decline.[22] PARO, a socially assistive robot (SAR), looks like a baby seal and engages patients by acting like a pet. It can recognise when a person is calling its name and can learn from repeated behaviour – if a patient scratches its neck after picking it up off the floor, it will look for a scratch every time it gets picked up.[23] PARO is approved by the US Food and Drug Administration as a therapeutic device, and a 2013 trial found that it had a moderate-to-large effect on patients' quality of life.[24]

What type of medical robots might we see in the future? Scientists are excited about the potential of "micro-bots". These tiny robots would move inside patients' bodies – helping to deliver drugs, address trouble spots (such as a fluid build-up), or repair organs. Researchers are also working on robots that are soft and resemble body tissue. In the US, researchers at MIT have developed prototype "squishy robots" that can switch between hard and soft states and could, in theory, move through the body without damaging organs.

3. Justice & security: Online dispute resolution and predictive policing

AI is already in play in the legal world. Courts use automatic speech recognition to dictate court records outlining who said what during a trial. Judges and lawyers use apps like ROSS Intelligence, built on

IBM's Watson platform, to post questions such as "Is a bankrupt company allowed to do business?". The app delivers instant answers, complete with citations and useful references to legislation or case law.

In time, AI could usher in a new generation of automated online courts, particularly for the small civil disputes that often clog up judicial systems. Canada is launching an online tribunal for small civil disputes that will allow claimants to negotiate with the other party and, failing that, face an online adjudication (run by humans). AI could enhance the system by "predicting" the outcome of a dispute before claimants begin. An algorithm has already been developed that can predict the results of more than 7,000 US Supreme Court cases with more than 70% accuracy, using only data that was available before the case.[25] If embedded into an online court, such predictive algorithms could encourage claimants to drop their claim (if ill-advised) or encourage the other party to settle. They could also be used by governments to channel legal aid more effectively, by identifying those who have a worthy case but no financial means of pursuing it.

"Why should the police only show up after the crime has been committed?"- Professor Tom Davenport, Babson College.

Police and security services are also using AI. Facial-recognition algorithms have been closely studied, and there is excitement over recent enhancements that allow them to recognise somebody even when their face is obscured. As revealed by Edward Snowden, the US National Security Agency also uses voice recognition software to convert phone calls into text in order to make the contents easier to search.[26]

Police are especially interested in using AI for "predictive policing". As Tom Davenport, a professor at Babson College, put it, "Why should the police only show up after the crime has been committed?". US firm PredPol analyses a feed of data on location, place and time of crimes to predict "hotspots" (areas of 500 feet squared) where crime is likely to happen within the next 12 hours. A study published in October 2015 found that the algorithm was able to predict 4.7% of crimes in Los Angeles, compared with 2.1% for experienced analysts. It concluded that deploying extra police in hotspot areas would save the Los Angeles Police Department US$9m per year.[27]

In Germany, researchers at the Institute for Pattern-Based Prediction Techniques have developed an algorithm for predicting burglaries based on the "near repeat" concept – ie, in an area where a burglary happens, repeated offences can be expected nearby within a short time frame. The algorithm predicts burglaries within a radius of about 250 metres, and a time window of between 24 hours and seven days. The institute claims that in the 18 months since its implementation in certain trial cities, arrests have doubled thanks to additional patrolling, and the number of burglaries has fallen by as much as 30%.[28] However, such approaches do raise ethical questions. For instance, if algorithms suggest that a crime is more likely in areas populated by certain ethnic groups, should police carry out more intensive patrols, or this a new form of racial discrimination?

Newer algorithms are looking beyond past crime data to inform their predictions. In 2015, researchers at the University of Virginia examined how Twitter posts could be assessed to predict crime (although the legal environment for this activity is hazy in many countries). Their algorithm also drew on weather forecasts – different types of extreme weather conditions have been shown to lead to spikes in crime.[29] The researchers claim that its accuracy is greater than that of models that use only historical crime data.[30]

Predictive policing can also come in other guises. In the wake of the marathon bombing of 2013, the city of Boston trialled predictive surveillance cameras. The AISight (pronounced "eyesight") platform, also in use in Chicago and Washington DC, starts by learning when a surveillance camera is showing "typical behaviour", such as somebody walking normally along a street. It then learns "untypical behaviour" that is associated with crimes, such as unusual loitering or a flurry of movement that may indicate that a fight is breaking out. It can then monitor surveillance cameras for abnormal behaviour, and send alerts to authorities when it spots something. Unsurprisingly, the system has aroused privacy concerns, although supporters argue that it is less damaging than more discriminatory attempts to prevent crime, such as stop-and-search interrogations based on racial profiling.

Justice and policing – The benefits of prediction

Predicting the likelihood of somebody re-offending	→	Decisions on parole and length of prison sentences
Predicting crime hotspots	→	Assigning extra police cover in risky areas
Predicting the outcome of a court case	→	Stronger incentives to mediate early and avoid court

Source: EIU

4. Administration: Automating visa processing, patent applications, and fraud detection

"If the qualification guidelines for pensions or visas are clear, AI can speed up processing"
- Andy Chun, Associate Professor of Computer Science at City University in Hong Kong.

A significant amount of day-to-day government bureaucracy is routine and based on deciding whether a person qualifies for something – be it a pension top-up or a visa. Much like marking exam papers, civil servants must apply several rules to each case, which can lead to backlogs and mistakes creeping in. If the qualification guidelines for such processes are clear, AI can speed up processing, according to Andy Chun, associate professor of computer science at City University in Hong Kong.

Chun worked on an algorithm for the Hong Kong government to process immigration, passport and visa applications. With millions of forms received yearly, the immigration office had previously struggled to meet demand. In an interview with the Economist Intelligence Unit, Chun explained that the algorithm approves some applications, rejects others, and classifies the remainder as "grey areas" where human judgement is needed. In these cases, the algorithm absorbs the choices that humans make to allow for future automation.

IP Australia, the country's intellectual property agency, is automating patent searches – the process by which a proposed invention is examined against existing inventions. A similar approach could be used to detect tax fraud. Today, governments rely on forensic accountants and lawyers wading through mountains of paperwork, such as annual business filings, to detect possible cases of tax fraud. An MIT researcher, Jacob Rosen, has explored an AI-led alternative. Rosen and his colleagues trained an algorithm to recognise specific combinations of transactions and company partnership structures that were often used in a specific tax dodge and unleashed it on new data.[31]

5. Transactional services: Personal assistants and "helperbots"

As explained above, when citizens apply for something – be it a new passport or registering ownership of a property – AI can help governments automate the approval process. However, AI can also help to enhance the experience of the citizen. In recent years, governments have tried to move these transactional services online, but uptake is often low. For instance, in the UK more than 50% of vehicle tax payments are still sent by post, even though 75% of British drivers buy their car insurance online. This carries a heavy cost. The UK's Cabinet Office estimated that a digital transaction can be up to 20 times cheaper than a telephone transaction, 30 times cheaper than a postal transaction, and 50 times cheaper than a face-to-face transaction.[32]

The benefits of digitisation – Cost of delivering services in the UK

Service	Digital take-up among users	Average cost per transaction
1. Customs transactions	99.9%	£0.1
2. Trade mark renewals	66.0%	£3.0
3. Driving licence renewals	30.0%	£10.3
4. Outpatient appointments	12.6%	£36.4
5. Income support claims	0.0%	£137.0

Sources: UK Cabinet Office, EIU

One way to improve uptake is to personalise digital services. Rather than offering pages of densely written "frequently asked questions", Singapore's government is piloting IBM's Watson as a "virtual assistant", much like Apple's Siri. It will allow a citizen to tell Watson, in natural language, exactly

"New personal assistants could answer everything from 'Am I eligible for a pension or benefit?' to 'How do I get a driver's licence?'
- Paul Macmillan, Deloitte.

what it wants to do. Watson will prompt them for more details, search through thousands of potential answers, and return the most appropriate one. According to Paul Macmillan, Deloitte's public-sector industry leader based in Canada, such personal assistants could understand and answer everything from "Am I eligible for a pension or benefit?" to "How do I get a driver's licence?". The system can constantly improve its answer quality by asking the citizen if they thought their issue had been resolved.

This new breed of digital service does carry the risk of exacerbating the digital divide in societies by alienating those who are not able to use digital services. In the short term, governments have responded by setting up "digital kiosks" where humans assist users to carry out the service in question. However, an alternative approach is to embed the virtual assistants offered by Watson into a helper robot that could scan people's details and physical documents.

Such "helperbots" are already being tested in the private sector. As Gerald Wang, program manager for Asia-Pacific at IDC Government Insight, pointed out, Henn na, a Japanese hotel, has used helperbots to automate its check-in process. The robots also store luggage and check room cleanliness. The process is not seamless, however. Visitors have claimed that helperbots struggle when dealing with unexpected obstacles, such as visitors forgetting their passports. However, according to Mr Wang, their introduction "shows what can be achieved".

6. Transport and emergencies: Moderating the impact of urbanisation

In 1950, only 30% of the world's population lived in urban areas. By 2030, this will hit 60%, with almost 10% living in "megacities" of 10m or more people.[33] Many urban transport systems are already creaking and require regular maintenance. In Hong Kong, AI algorithms are used to schedule the 2,600 subway repair jobs that take place every week. They do so by identifying opportunities to combine different repairs and evaluating criteria, such as local noise regulations. Today, the subway enjoys a 99.9% on-time record – far ahead of London or New York.[34]

The repair work is still carried out by humans. In time, robots could play a greater role. In the UK, the University of Leeds recently won a £4.2m (US$6.4m) grant to help create "self-repairing cities", where small robots identify and repair everything from potholes to streetlights and utility pipes.[35] Despite the eye-catching name, in the short term robots are likely be more useful for monitoring and assessing infrastructure rather than repairing it, given the advanced dexterity that the latter often requires.[36]

Urbanisation also risks exacerbating pollution, as China has borne witness to. According to a recent study, air pollution contributes to 1.6m deaths in China every year – one-sixth of all deaths in the country.[37] On a given day, the severity of pollution depends on various factors including temperature, wind speed, traffic, the operations of factories, and the previous day's air quality. In August 2015, IBM China revealed that it is working with Chinese government agencies on a programme to predict the severity of air pollution 72 hours in advance. It claims that its predictions are 30% more precise than those derived through conventional approaches.[38] The goal now is to expand the length of the predictions, giving the authorities more time to intervene – for instance, by restricting or diverting traffic, or even temporarily closing factories.

AI can help governments create better urban-planning strategies. Using software developed by the US Defense Advanced Research Projects Agency (DARPA), Singapore is analysing huge masses of data, such as anonymised geolocation data from mobile phones, to help urban planners identify crowded areas, popular routes, and lunch spots, and to then use this information to make recommendations about where to build new schools, hospitals, cycle lanes and bus routes.[39]

Disaster management is another urban-planning application. In the US, the state of California is trialling AI technology developed by start-up One Concern which can predict what areas of a town are likely to be worst affected by an earthquake. The system uses data on the age and construction materials of buildings. When the early signs of an earthquake are identified, it combines this with seismic data, so that emergency resources can be targeted. Robots will increasingly work alongside humans to carry out such emergency efforts. In Japan, following the Fukushima nuclear power plant explosion of 2011, drones used infra-red sensors to survey and gather data from locations too dangerous for humans.

How should governments respond?

For governments, this development of robots and AI holds significant promise, but also raises challenges that need to be managed. This requires a multi-faceted response.

1. Invest in trials and manage accountability

All government agencies should be asking how robots and AI – and the automation, personalisation and prediction that they offer – could enhance their work. In many cases, applications will build on what has been happening for years. For instance, police forces have long monitored areas following a robbery to prevent future incidents. Predictive policing algorithms are a logical, more sophisticated, extension of this.

Expectations must be kept in check. Most trials will need close involvement from human staff initially, and will work best in narrow, tightly defined, areas (such as trying to predict burglaries rather than all types of crime). Moreover, "predicting" should not be confused with "solving". Predicting crime and intervening to stop it does nothing to address its root causes. Predicting who is most likely to develop cancer is certainly valuable, but potential sufferers will still need to address difficult questions about how to prevent, or treat, the disease (see chapter 2).

It is also critical that accountability is not automated when a task is. "Black box" algorithms whose rationale or logic are not understood will not be accepted by key stakeholders. Some AI suppliers have recognised this. IBM's new "Watson Paths" service provides doctors and medical practitioners with a step-by-step explanation of how it reached its conclusions.

2. Support research and debate on ethical challenges

Robots and AI give rise to difficult ethical decisions. For instance, how does AI interpreting data from surveillance cameras affect privacy rights? What if a driverless car's efforts to save its own passenger risks causing a pile-up with the vehicles behind it? If a robot is programmed to remind people to take medicine, how should it proceed if a patient refuses? Allowing them to skip a dose could cause harm, but insisting would impinge on their autonomy.

Such debates have given rise to a new field, "machine ethics", which aims to give machines the ability to make appropriate choices – in other words, to tell right from wrong. In many cases philosophers work alongside computer scientists. In January 2015, the Future of Life Institute, set up by Jaan Tallinn (co-founder of Skype) and Max Tegmark (MIT professor), among others, to mitigate the existential risks facing humanity, published a set of research priorities to guide future AI work.[40] AI companies have also set up ethics boards to guide their work, while government-backed research institutes, including the US Office of Naval Research and the UK government's engineering-funding council, are evaluating the subject.

Despite what some media might report, the main concern is not that future AI might be "evil", or have any sentience whatsoever (ie, the ability to feel). Rather, the concern is that advanced AI may pursue its narrow objectives, even positive ones (such as passenger safety or patient health), in such a way that is misaligned with the wider objectives of humanity.[41] To explain the point, a stark "paperclip" example is often used. In this scenario, an AI is tasked with maximising the production of paperclips at a factory. As the AI becomes more advanced, it proceeds to convert growing swathes of the earth's materials, and later those of the universe, into a massive number of paperclips. Although the example is simplified, it explains a broader concern – that the narrow goals of AI become out of sync, or "misaligned", with the broader interests of humanity.

3. Foster new thinking about the jobs challenge

Trying to predict the impact of robots and AI on jobs is difficult. Participants on both sides make valid points. Positive commentators argue that past technological improvements – from the industrial revolution to the rise of the Internet – have always led to increased productivity and new types of jobs. This, in turn, has made most of society better off (even if individual groups, such as farmers or miners, have suffered).

However, critics retort that past technological developments are a poor guide because robots and AI have the potential to replace a far wider set of jobs, including many skilled professions in fields as diverse as healthcare, law, and administration. Furthermore, the new technology-based firms that emerge are unlikely to be "job-heavy". Google and Facebook employ a fraction of the staff that more traditional firms of similar sizes employ, such as General Motors or Wal-Mart.

As a result, the rise of robots and AI has the potential to exacerbate two challenges facing governments: widening inequality and long-term unemployment. While productivity in a country may increase, the benefits may accrue to a narrow pool of investors, rather than to employees. In response, commentators such as Martin Ford, author of *Rise of the Robots,* have suggested a guaranteed income for every citizen. This "digital dividend" would be recognition of the fact that much of the new advances in robots and AI rely on research that was originally funded by governments. As Ford has pointed out, such a policy would be politically challenging in many countries. An alternative approach suggested by Jerry Kaplan, author of *Humans Need Not Apply,* is for governments to try and spread firm ownership more broadly by reducing the corporate tax rate for firms with a significant number of individual shareholders. This would allow individuals to benefit more from the robots and AI revolution.

4. Invest in education, but not the traditional sort

The stock response to any technical challenge is to invest in education to "future-proof" a country's population. However, no type of conventional high-school or university education can adequately prepare students for a world where robots and AI are prominent. The speed of change is too great and nobody can predict what skills will be needed in ten years' time. Competency-based education programmes hold more promise. They focus on teaching individual skills (or competences) and can be completed at any stage in an employee's career. They can also be quickly designed and rolled out in response to companies' ever-changing needs.

Udacity, an online-education firm, has teamed up with companies such as AT&T to provide "nano-degrees" – job-related qualifications that can be completed in six to 12 months for $200 per month. Dev Bootcamp offers a nine-week course for code developers, paid for in part by a success fee. The firm charges employers for each graduate hired, after they successfully complete 100 days on the job.[42] To fund such programmes, Jerry Kaplan has called for companies to offer "job mortgages". Under this system, workers would commit to undertaking ongoing training as part of their employment contract. The cost of the programmes would be deducted from their future wages.[43]

5. Tackle the security issues at a global level

The development of LAWS – which could select and attack targets without human intervention – is closer than most imagine. Indeed, there is a first-mover advantage in their development. Once they become relatively straightforward to produce, military powers will struggle to avoid the temptation to gain an advantage over their foes. Once one country is thought to have them, others are likely to follow suit.

This has culminated in the "Campaign to Stop Killer Robots", fronted by an alliance of human rights groups and scientists. They call for a pre-emptive ban on developing and using LAWs, in the same way that blinding laser weapons and unexploded cluster bombs were banned in the past. However, a full ban is opposed by some countries, including the UK and the US, who have argued that existing law is sufficient to prevent the use of LAWs.

Others have questioned whether LAWs are ethically worse than traditional weapons. If they more accurately identify targets, while also meeting the traditional humanitarian rules of distinction, proportionality, and military necessity, this could result in fewer unintended deaths than traditional human-led warfare.

As with nuclear weapons, the best long-term solution is an international agreement with clear provisions on what countries can do. The UN has already held a series of meetings on LAWS under the auspices of the Convention on Certain Conventional Weapons in Geneva, Switzerland. The next week-long meeting will be held in April 2016. However, controlling the development of LAWs is likely to prove more difficult than nuclear weapons, as developing them in secret will be much easier and quicker.

Conclusion

Robots and AI have been heavily hyped in the popular media discourse, with advocates and sceptics each presenting dramatic visions of utopian, or dystopian, futures. Yet in this polarised kind of debate, many of the nuances and subtleties are lost.

On one hand, supporters tend to over-promise what their technologies can do, and often have vested interests in these technologies. On the other hand, the underlying trends that make robots and AI a reality are developing much faster than most people realise, and a tipping point in their development has been reached.

The range of tasks that robots and AI will soon be able to undertake is also far beyond what many people appreciate. This could dramatically enhance the work of governments – by automating and personalising services, and by better predicting challenges before they arise. However, robots and AI also pose risks to security, employment, and privacy, and raise knotty ethical challenges that require wider debate. Governments are right to progress robots and AI trials, but must also give considered thought to the challenges they bring.

Chapter 2: Genomic Medicine

Executive Summary

Genomic medicine uses an individual's genome – ie, their unique set of genes and DNA – to personalise their healthcare treatment. Genomic medicine's advance has been boosted by two major developments. First, new technology has made it possible, and affordable, for anybody to quickly understand their own genome. Second, new gene-editing tools may allow practitioners to "find and replace" the mutations within genes that give rise to disorders.

Much of genomic medicine is relatively straightforward. Rare disorders caused by mutations in single genes are already being treated through gene editing. In time, these disorders may be eradicated altogether. For more common disorders, such as cancer, the response is more complex. However, patients' genomic data could lead to more sophisticated preventative measures, better detection, and personalised treatments. Other potential applications of genomic medicine are mind-boggling. Researchers are exploring whether gene editing could make animal organs suitable for human transplant, and whether "gene drives" in mosquito populations could help to eradicate malaria.

The fast pace of development has led to ethical concerns. Some worry that prospective parents may try to edit desirable traits into their embryos' genes, to try and increase their baby's attractiveness or intelligence. This, critics argue, is the fast route back to eugenics and governments need to respond appropriately.

This chapter starts with an overview of what exactly genomic medicine is and the recent advances that have led to such excitement. It then examines three key ways in which genomic medicine could transform healthcare delivery. The chapter concludes with suggestions for government leaders on how to respond.

Key definitions

Biology terms

Organism

An organism is any living biological entity. Examples include people, animals, plants, and bacteria. Organisms are made up of cells.

Cells

The human body is composed of trillions of cells. They are the smallest unit of life that can replicate independently, and make up the tissue in organs such as the brain, skin and lungs.

Chromosomes

Most human cells contain a set of 46 chromosomes, which in turn contain most of that person's DNA. These 46 chromosomes come in 23 pairs. One chromosome in each pair is inherited from the mother, and one from the father.

DNA

DNA (or deoxyribonucleic acid) is mainly located in chromosomes. It provides a set of instructions for how a person will look, function, develop, and reproduce. DNA is made up of sequences of four chemical "blocks", or bases: adenine (A), cytosine (C), guanine (G) and thymine (T).

Genes

Genes are individual "sequences" of DNA that determine the physical traits that a person inherits and their propensity to develop certain diseases. For example, the sequence ATCGTT might be an instruction for blue eyes. Individuals inherit two versions of each gene – one from each parent.

Proteins

Some genes instruct the body on how to make different proteins. Proteins are necessary for an organism to develop, survive and reproduce. For instance, the BRCA1 gene is known as a "tumour suppressor" because it can instruct a protein to repair breast tissue.

Genome

A genome is an organism's complete set of DNA. For a human, it contains around three billion DNA letters (or bases), and around 20,000 genes, located on 46 chromosomes. Most cells in a person's body contain the same, unique genome.

Genome sequencing

Genome sequencing is undertaken in a laboratory, and determines the complete DNA sequence of an organism – ie, how the DNA "blocks", or bases, are ordered.

Genetic variation

99.9% of DNA is identical in all people in the world, regardless of race, gender or size. However, the remaining "genetic variation" explains some of the common differences in appearance, disease susceptibility, and other traits.

Gene mutations

Gene mutations occur when an individual's gene becomes different to that which is found in most people. These mutations could be inherited from one's parents, or they could develop due to environmental factors such as exposure to toxins.

Gene disorders

Up to 10,000 diseases, called monogenic disorders, are caused by a mutation in a single gene. Other, more complex disorders, such as most cancers, are caused by a combination of multiple gene mutations and external factors such as diet and exposure to toxins.

Gene therapy

Gene therapy replaces a mutated gene with a healthy copy, or introduces a new gene to help fight a disease. A new technology, CRISPR-Cas9, allows gene mutations to be "edited" and replaced with "correct" genes. However, it has not yet been used on humans.

Gene disorders

Cystic fibrosis

Cystic fibrosis is a life-threatening disease. A mutated gene causes a thick build-up of mucus in the lungs, pancreas, liver, kidneys, and intestines. The build-up makes it hard to breathe and digest food, and leads to frequent infections.

Familial hypercholesterolaemia

A condition that causes patients' "bad cholesterol" levels to be higher than normal, increasing the risk of heart disease and heart attacks at an early age.

Haemophilia

Haemophilia is a group of disorders that can be life-threatening. Mutated genes mean that a patient's blood does not clot properly, potentially leading to excessive bleeding. Internal bleeding can damage key organs and tissues.

Huntington's disease

Huntington's disease causes the progressive breakdown of nerve cells in the brain. Over time it increasingly affects a patient's movement, cognition and behaviour.

Mitochondrial diseases

Mitochondrial disease is a group of disorders that are caused by mutations in mitochondrial DNA, which converts food into energy. Symptoms include loss of muscle coordination, learning disabilities, heart disease, respiratory disorders, and dementia.

Muscular dystrophy

A group of conditions that gradually cause the muscles to weaken, leading to an increasing level of disability. One of the most common forms is “Duchenne muscular dystrophy”; men with the condition will usually live only into their 20s or 30s.

Maple syrup urine disease (MSUD)

A condition caused by a gene defect which prevents the body from breaking down certain parts of proteins, leading to a buildup of chemicals in the blood. In the most severe form, MSUD can damage the brain during times of physical stress (such as infection, fever, or not eating for a long time).

Sickle cell disease

A group of disorders that cause the red blood cells to become rigid and sickle-shaped, in contrast to normal red blood cells, which are flexible and disc-shaped. The abnormal cells can block blood vessels, resulting in tissue and organ damage and severe pain. One positive effect is that sufferers are protected from malaria.

Severe combined immunodeficiency (SCID)

A group of potentially fatal disorders in which a gene mutation results in patients being born without a functioning immune system. This makes them vulnerable to severe and recurrent infections.

Tay-Sachs disease

A fatal disorder that primarily occurs in children. It occurs because a mutated gene can no longer produce a specific enzyme, resulting in a fatty substance building up in brain cells and nerve cells which destroys the patient’s nervous system.

Thalassaemia

Thalassaemia is a group of disorders in which the body makes an abnormal form of haemoglobin, the protein in red blood cells that carries oxygen. If left untreated, it can cause organ damage, liver disease, and heart failure.

Source: EIU, Genetic Home Reference, NHS

Background

In May 2013 the actress Angelina Jolie underwent a much-publicised double mastectomy. She did so after being informed that she has a faulty version of the BRCA1 gene, giving her an 87% chance of developing breast cancer.[1] A year later, researchers found that the number of women in the UK who had undergone BRCA testing had doubled – a phenomenon now referred to as the "Angelina Jolie effect".[2]

Although she may not have planned it, Ms Jolie gave a significant boost to the field of *genomic medicine* – broadly defined as using an individual's genomic information (or DNA) in their clinical care. In recent years, the field has enjoyed landmark breakthroughs that could lead to a revolution in how diseases are diagnosed, treated, prevented, and even eradicated.

What is genomic medicine?

A move away from one-size-fits-all

If a person feels unwell they typically visit a doctor, usually after their symptoms become prolonged or pronounced. If they are lucky, they will make that visit in good time and the doctor will make a diagnosis by checking their symptoms and asking questions about family history and lifestyle. For more complex conditions, various tests and the involvement of specialists may be needed.

Once diagnosed, the patient will embark on a treatment plan. While the impact of a disease can feel very personal, the treatment usually isn't. Patients receive treatment based on nationally accepted procedures and protocols. If the first treatment doesn't work, a different approach is tried – an iterative process that can turn into a race against time for more serious diseases.

Genomic medicine (sometimes referred to as personalised medicine or precision medicine) promises a more nuanced approach. It takes as its premise the fact that each person's biological make-up is unique and so their diagnosis and treatment should be as well – using that individual's unique genomic information, or DNA. Its advance has been boosted by two major developments.

First, the human genome was successfully sequenced in 2001. This provided a set of "blueprints" for how the human body works. It was followed by rapid technological advances over the next 14 years that made it possible for anybody to quickly and cheaply sequence their own genome. Second, sophisticated "gene-editing" tools have been developed that can potentially modify faulty genes and help treat, or prevent, certain diseases.

> Genomic medicine has been boosted by the huge fall in sequencing costs, and the rise of new gene editing tools.

The mapping of the human genome and the rise of "next-gen" sequencing

In 2001 the Human Genome Project (HGP), the world's largest collaborative biological research project, announced the first ever successful sequencing of the human genome. In terms of scale, this has been likened to an "internal" voyage of human discovery on a par with the external voyage that brought man to the moon.[3]

A person's genome is their full set of DNA. It is located in most cells in their body and is packaged into 23 pairs of chromosomes. One chromosome in each pair is inherited from the person's mother and one from the father. Each chromosome is made up of individual sequences of DNA, called genes.

Much like how letters in the alphabet are arranged to form words, four basic blocks (A, C, G and T) of DNA are arranged to form genes. The HGP discovered that a person has approximately 20,500 genes – far fewer than previously thought. It also identified these genes' locations and how their basic blocks are ordered.

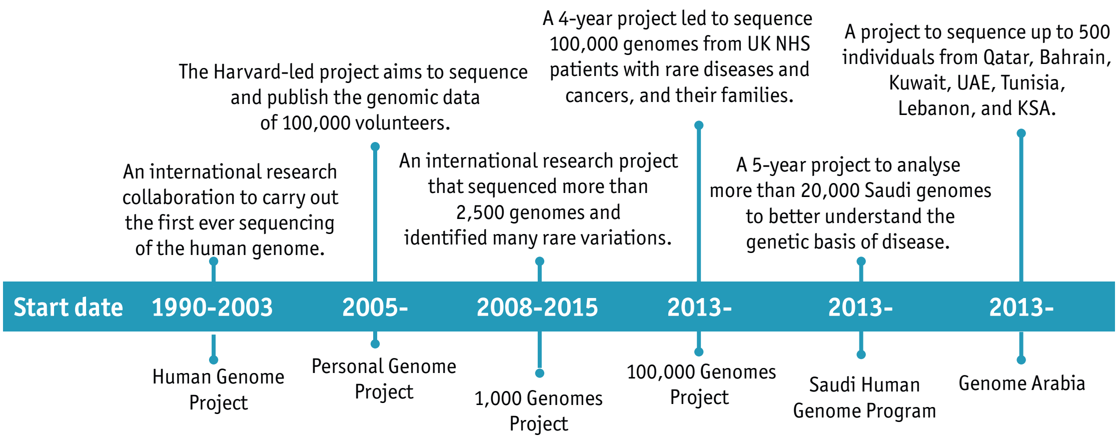
This is important because a person's genes determine their traits – ie, how they look and function. They also determine that person's propensity to develop certain diseases. This is because genes provide instructions to the body for how to make proteins. Proteins, in turn, carry out key functions such as repairing cells or protecting against infections.

If the basic blocks in an individual gene become garbled or "mutated", it may be unable to produce the protein needed. For instance, the BRCA1 gene is known as a "tumour suppressor" because it can repair mutated DNA in breast tissue. If it becomes damaged by a mutation (as in Angelina Jolie's case), the risk of breast cancer increases.

99.9% of the DNA in human genomes is identical across all people. However, the remaining 0.1% (ie, a person's gene variations) is of huge importance. Some of these gene variations, or mutations, are inherited from our parents, while others are developed over time (due to smoking or exposure to toxins, for example). Some mutations are harmless, while others are associated with diseases. The impact of many remains unknown.

The HGP provided a vital starting point to the understanding of our genes. In the decade since it concluded, scientists launched a set of sequencing projects to understand how genes (and gene mutations) vary across different people. For instance, how do the genes of Alzheimer's patients differ from those who do not have the disease? How do the genes of patients that respond well to treatment differ from those who do not?

Initiatives to sequence genomes around the world

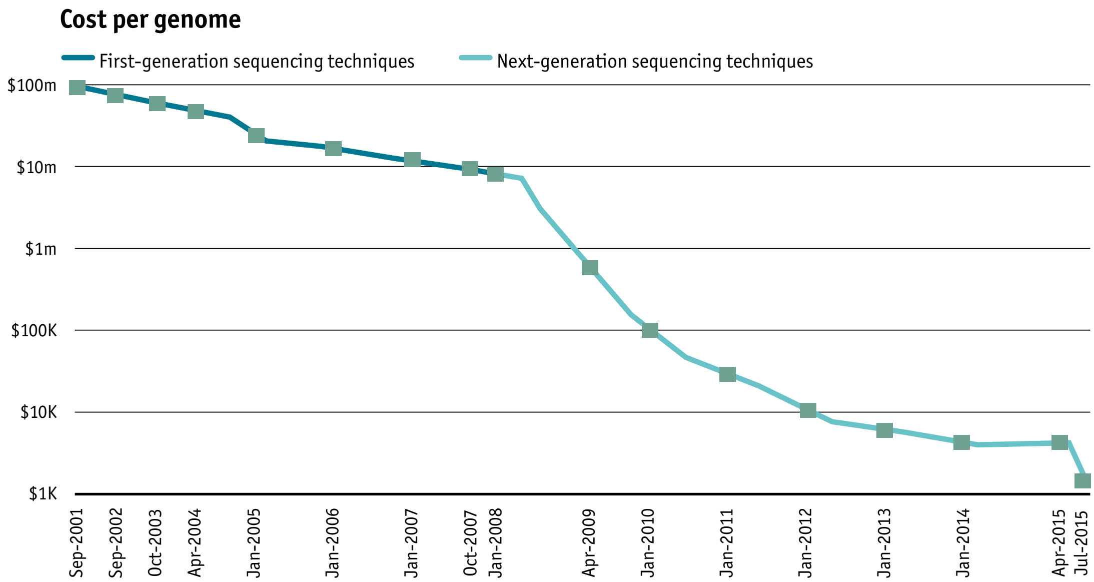


Source: EIU

These projects have been made possible by the development of "next-gen" sequencing tools which have sharply reduced the costs and time needed to sequence an individual genome (see graphic, below). A whole genome can now be sequenced for little more than US$1,000. This represents a huge fall from the cost of more than $100m of 15 years ago. This fall means that sequencing full populations is now feasible. Genome sequencing has left university laboratories and entered the wider civilian world. Today, companies such as Mapmygenome and 23andMe allow individuals to provide a saliva sample by post and pay little more than US$100 to have parts of their own genome sequenced.

A whole human genome can now be sequenced for little more than US$1,000.

The cost of sequencing an entire human genome



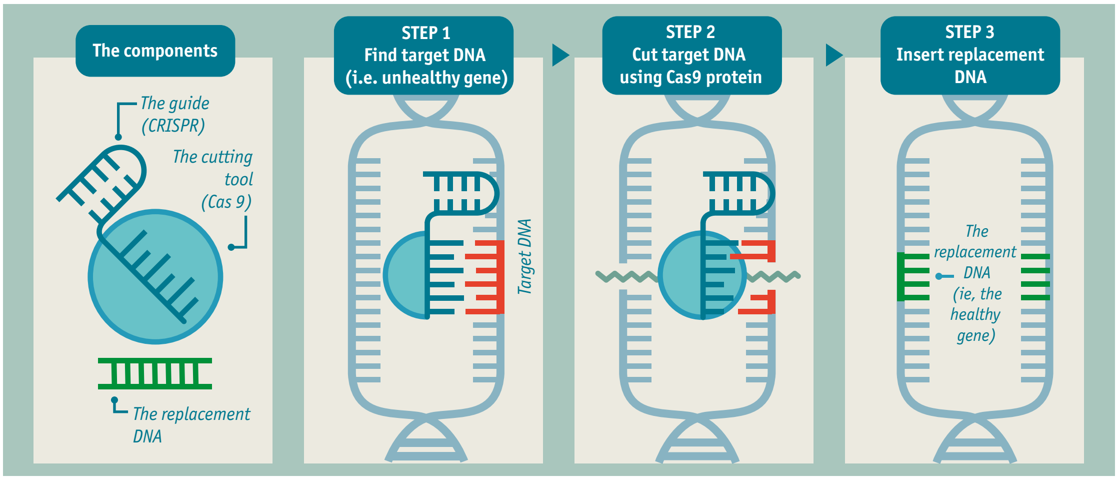
Source: National Human Genome Research Institute

Gene editing: A "find and replace" button for mutated genes?

It is quite easy to imagine a world where everybody sequences their genome to better understand their own gene mutations and their propensity to develop certain diseases. However, a second development promises something even more radical – what if everybody could alter, or "edit", their own genes? Rather than just knowing that you have a mutated gene and a high likelihood of developing a certain disease, you could take action and fix the faulty gene in question.

Attempts to carry out such gene editing, or gene therapy, are not new. However, in 2012, a highly sophisticated new technique emerged. Discovered by the biochemists Jennifer A. Doudna and Emmanuelle Charpentier, CRISPR-Cas9 allows scientists to do two things. First, it can identify a target gene mutation that needs to be altered. Second, it can snip the defective gene and replace it with a correct one – in a similar way to how the "find and replace" function works on a computer.

Gene editing – How the CRISPR-Cas9 process works



Sources: EIU, The Economist

The use of CRISPR-Cas9 has grown sharply in recent years. It has been tested on mice to cure versions of liver disease.[4] Agriculture companies, such as Monsanto, are using it to try and make grains more resistant to disease. Scientists at Harvard are even using CRISPR-Cas9 in efforts to revive woolly mammoths (by editing the DNA of ancient mammoths into that of Asian elephants). The goal is to develop a new breed of mammal that can survive in the extreme and cold conditions of the tundra and boreal forests in Eurasia. The extinction of mammoths in these forests has eroded grasslands, and caused permafrost to melt. This, in turn, is releasing large amounts of trapped greenhouse gases, hurting efforts to address climate change.[5]

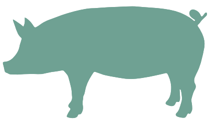
CRISPR-Cas9 is being used to cure mice of liver disease and to try and revive the woolly mammoth.

CRISPR-Cas9 experiments to date

Curing liver disease in mice

In 2014, MIT researchers cured mice of a rare liver disorder by replacing the gene mutation responsible.

Preparing pig organs for transplant



Dr George Church and researchers at Harvard Medical School are editing pig embryos as part of an attempt to make them safe for human organ transplants.

Editing human embryos

In 2015, researchers in China edited the genome of human embryos for the first time, in an experiment to modify the gene responsible for β-thalassaemia (an inherited blood disorder).

Source: EIU

However, CRISPR-Cas9 has not yet been used to edit the genes of humans. It is this possibility, and the possibility that human embryos might be edited, that has given rise to controversy and fierce debate. Supporters argue that it could be used to cure devastating diseases. Critics counter that it is a slippery slope that could lead to a new generation of "designer babies".

How will genomic medicine impact healthcare?

Discussions about genomic medicine often give rise to confusion. On the one hand, suggestions of designer babies imply that a highly advanced, albeit dystopian, future will soon be upon us. On the other hand, the actual use of genomic data in day-to-day healthcare delivery remains limited. So what will the actual impact be? Three areas are worthy of close attention.

How will genomic medicine affect healthcare?

The challenge		How can genomic medicine help?
Rare disorders (eg, cystic fibrosis)	→	Diagnosing, treating and eradicating
Common diseases (eg, cancer, alzheimer's)	→	Enhancing screening, prevention and treatment
Epidemic diseases and a lack of organ donors	→	Gene drives and next-gen transplants

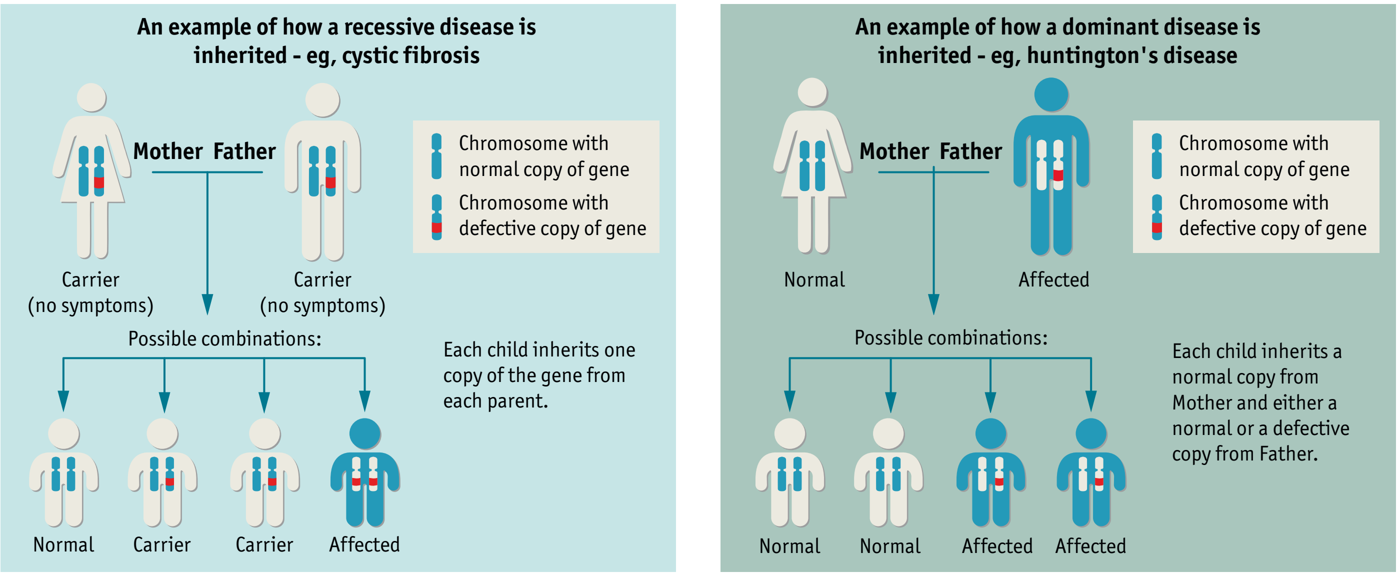
Source: EIU

1. The low-hanging fruit: Eradicating rare disorders

"Monogenic disorder" is a term that is rarely heard. However, for parents around the world such disorders have caused untold anguish. Examples include β-thalassaemia, Huntington's disease, cystic fibrosis and haemophilia. When children are affected, doctors often struggle to make a diagnosis, and even if a diagnosis is made there is often no treatment available. The resulting physical and mental toll can be devastating.

When a child is born they possess two versions of each gene – one inherited from each parent. Monogenic disorders are caused by a mutation in a single gene. In the case of "recessive" disorders, both versions of the child's gene must be mutated for the disorder to develop. If only one version of the gene is mutated the child will not be affected but they will become a "carrier". If a carrier has a child with a fellow carrier, there is a 25% probability that their child will be affected by the disorder. In the case of "dominant" disorders, only one version of a child's gene needs to be mutated for the disorder to develop, so the probability of inheriting the disease is even higher, at 50% (see graphic below).

How do dominant and recessive disorders work?



Sources: EIU, The Genetic Science Learning Center at The University of Utah

Monogenic disorders disproportionately affect children. They are individually rare, but in aggregate affect more than 1% of the population. Sadly, because they are rare, few treatments have been developed, giving rise to the name “orphan disorders”. It is victims of these orphan disorders, and their families, who have arguably the most to gain from genomic medicine.

Common monogenic disorders and their impact

Disorder	Prevalence (approximate)	Possible impact (if untreated)
Familial hypercholesterolaemia	1 in 500	Very high cholesterol; heart attacks at an early age
Sickle cell disease	1 in 500	Repeated infections; sharp muscle pain; delayed development
Tay-Sachs disease	1 in 3,600	Loss of muscle strength; seizures; loss of vision and hearing; paralysis
Cystic fibrosis	1 in 3,600	Chronic coughing; chest infections; and digestion problems
Haemophilia	1 in 5,000	Excessive bleeding; deep bruises; sudden pain; and swelling
Duchenne muscular dystrophy	1 in 7,000	Muscle weakness and wasting; heart problems
Huntington's disease	1 in 15,000	Depression; involuntary jerking; learning difficulties; poor coordination

Source: EIU

Identifying and diagnosing the disorder

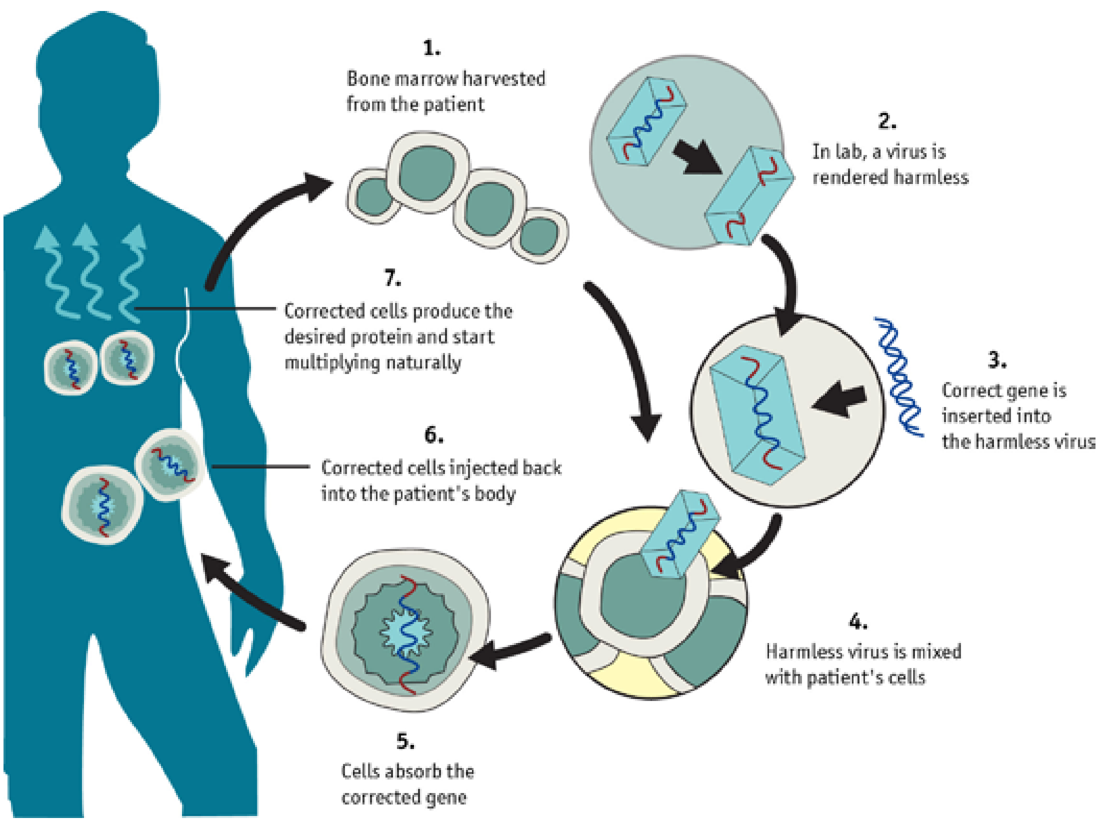
In the past, many of these disorders went undiagnosed simply because doctors were unfamiliar with the conditions. Suffering children endured endless tests while their health deteriorated. Today, scientists are sequencing the genomes of those affected to identify the gene mutations responsible. Since the HGP, the number of single-gene disorders that have been identified has risen from 61 to more than 5,000. However, there are still more than 1,500 rare diseases whose genetic cause is yet to be understood.[6]

Treating disease through new types of gene therapy

As monogenic disorders are caused by a single mutation they are also more straightforward to treat than many more common diseases. For instance, children suffering from SCID-X1 (severe combined immunodeficiency) are born with a mutation in the IL2RG gene which causes a faulty immune system. They can easily develop infectious diseases and are commonly referred to as "bubble babies" – after the famous case of David Vetter who had to live in a large sterile bubble. For a long time, the only treatment available was a bone marrow transplant – and suitable donors are difficult to find.

A gene therapy programme, led by the Great Ormond Street Hospital (GOSH) in London and the Necker Children's Hospital of Paris, offers a different approach modelled on how viruses work. In their laboratory, a virus is first altered so that it cannot reproduce. The child's bone marrow (which contains the faulty gene) is then extracted. The "correct" gene is inserted into the harmless virus, implanted into the bone marrow, and then injected back into the patient.

How the GOSH treatment works



Sources: EIU, Sgugenetics, GOSH

The process to develop the treatment has not been completely smooth. In an early trial, the treatment activated some patients' genes in the wrong way. This caused cells to proliferate abnormally, leading to patients developing leukaemia. However, alterations have been made, and recently treated SCID-X1 patients are healthy. According to Dr Bobby Gaspar, who is leading the GOSH team, this is the first monogenic disease to be "cured" through gene therapy. This type of gene therapy is the most straightforward to undertake because it is done *ex vivo* – ie, outside the body, in the laboratory. Sangamo BioSciences, a US biopharmaceutical company, is applying similar approaches to treat β-thalassaemia, haemophilia (two blood disorders) and even HIV.

"SCID-X1 is the first monogenic disorder to be cured via gene therapy."
Dr Bobby Gaspar, Great Ormond Street Hospital.

However, when a disorder affects the brain or eyes it not possible to simply take the cells out, edit the genes, and put the cells back in. In such scenarios, in vivo (or in-body) gene therapy is required. Efforts in this area are promising. Sanfilippo A syndrome, a rare monogenic disorder caused by mutations in the SGSH gene, causes a toxic substance to form on the brain, leading to severe neurodegeneration. Sufferers typically lose most of their cognitive abilities early on, develop severe sleep disorders, and become hyperactive. They rarely live beyond their teens.

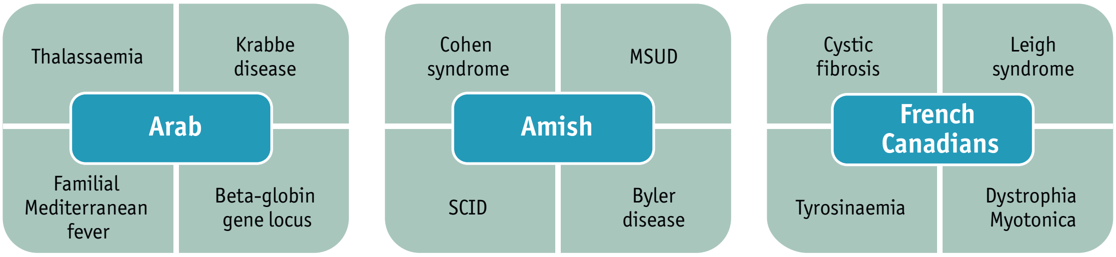
Lysogene is a French company founded by the mother of a child affected by the syndrome. It has developed a liquid drug containing a healthy version of the gene. This is injected directly into the brain, through an approach known as a "viral vector", and is able to clean the toxic material. In trials, patients have shown cognitive and behavioural improvements and the drug is now heading to the pivotal clinical phase, the final step before a formal application for licensing and manufacturing for commercial purposes.

Preventing disease through screening

While the treatments outlined above are impressive, an even more revolutionary approach would be preventing diseases occurring altogether. A first step is to sequence the genomes of prospective parents to see if they are carriers of the gene mutations in question. This is especially important in communities where relatives are allowed to marry, as the probability of both parents carrying the gene mutation is higher.

In Saudi Arabia, marriage between cousins is permitted and the country has high levels of single-gene disorders.[7] As a result, the Ministry of Health now requires all couples wishing to marry to undergo premarital genetic screening. If both parties are found to be carriers, they are not prevented from marrying, but special court approval is required. Since the initiative began, the number of voluntary wedding cancellations has increased, and the prevalence of β-thalassaemia has declined.[8] In recognition of the growing importance of genomics, the government launched the Saudi Human Genome Program to sequence the genes of 100,000 Saudis.

Communities at high risk of genetic disorders



Source: EIU

Eradicating the disease – The dawn of embryo editing?

The most controversial aspect of genomic medicine is the proposed editing of human embryos, to “edit out” the gene mutations that give rise to disorders. Unlike the gene therapy outlined above, the editing of embryos would affect the sperm and eggs cells and so any changes would also be passed on to future generations.

For supporters of gene editing, this is an opportunity to eradicate disorders altogether. However, critics warn of unintended consequences since much of how genes work remains unknown. Critics also fear that allowing this procedure, even in a narrow form, could be a slippery slope towards more controversial forms of gene editing. As researchers better understand the role of genes, prospective parents may not wish simply to prevent diseases. They may wish to edit other desirable traits into their

Case study The troubling history of eugenics

Eugenics, derived from the Greek words for “good origin”, first gained popularity in the late 19th century when an English intellectual, Francis Galton, concluded that the superior intelligence of the English upper classes was hereditary. Galton advocated a selective breeding programme for humans that would result in a “highly gifted race”.

Eugenics took root in the US in the 1920s when prominent academics began to gather data on families’ “pedigrees”, and in particular the presence of “undesirable” traits such as mental disability and criminality. Eugenics expanded into a social movement with the launch of the American Eugenics Society, which promoted eugenics principles and held “fitter family” and “better baby” competitions.

Efforts then turned to eradicating such “undesirable” traits in poor, migrant, and uneducated people. Led by Indiana and California, 30 states enacted forced sterilisation laws to prevent “undesirables” from reproducing. The disabled were targeted first, but those in poverty were also targeted. In total, between 1907 and 1963, 64,000 people were forcibly sterilised in the US. Germany’s Nazi movement openly sought to emulate the US eugenics movement by launching a “racial hygiene” programme aimed at maintaining the Aryan race. It was only after this that the US eugenics movement began to falter.

Source: Nature, EIU

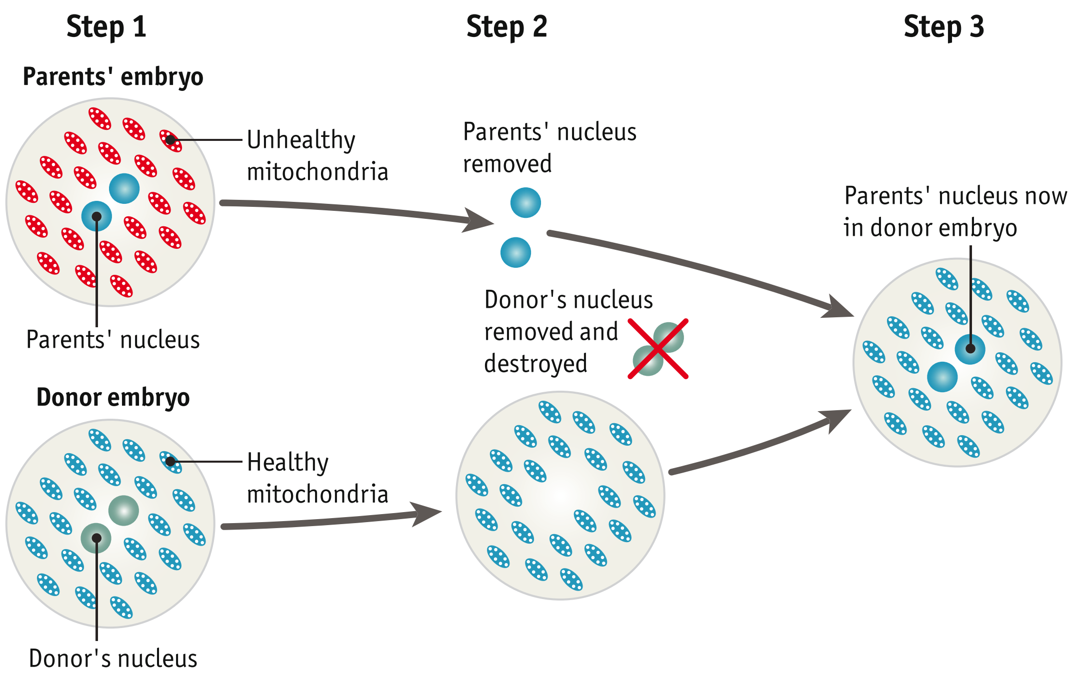
embryos, such as increasing their attractiveness or intelligence. This, critics argue, is akin to "playing God" and is the fast route back to eugenics.

The gene-editing debate was enlivened in April 2015 when scientists in China used CRISPR-Cas9 to edit the DNA of embryos to try to modify the gene responsible for β-thalassaemia. To forestall criticism, they used non-viable human embryos in the experiment (ie, those that could not result in a live birth).[9] The results were disappointing and many leading scientists criticised the study on technical grounds.

Despite the criticism, the editing of embryo DNA has recently been approved by the UK government, albeit in a different, narrower, form. A regulation approved in 2015 aims to prevent future cases of mitochondrial diseases. These are caused by mutations in a specific type of DNA and are passed down from mother to child. The impact on the child is devastating – muscular dystrophy and organ failure are common – and there is currently no cure available.

To prevent future cases, the UK parliament voted to approve the use of "three-parent IVF" (in vitro fertilisation). This involves taking a fertilised egg cell from the two parents; the nucleus of the cell (which contains most DNA, but not the mitochondrial sort) is then taken out and implanted in a healthy third-party donor egg. This egg is then transplanted into the mother's uterus, as in standard IVF. Opponents argue that three-parent IVF would dilute parenthood. They have also raised ethical concerns about children being permanently altered without their consent, and the risk of unintended consequences. Despite this, the legislation passed and the UK became the first country in the world to allow this kind of genetic modification of unborn children. The US and Australia are now considering the merits of the approach.

How does "three-parent" IVF work?



Source: HFEA

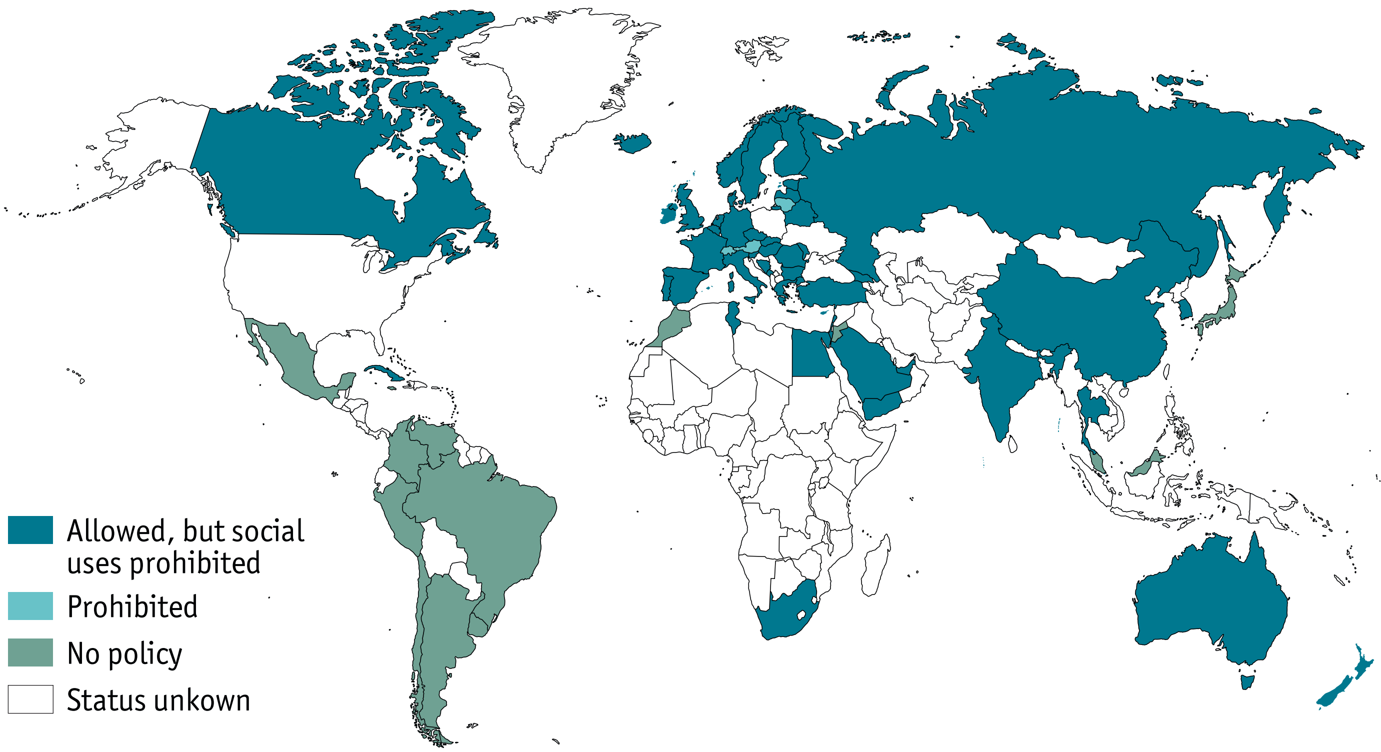
A way forward – Adapted IVF?

For parents who are carriers of gene mutations that give rise to disorders, but who still wish to have a child, a more straightforward alternative to embryo editing would be to undergo an adapted form of IVF.

In this process several eggs are fertilised. Each embryo is then screened and only one that is mutation-free is implanted in the mother's womb. This "pre-implantation genetic diagnosis" (PGD) is already legal in the UK, where it is monitored by the Human Fertilisation and Embryology Authority (HFEA), a national regulatory agency. However, PGD is permitted only for carriers of "sufficiently serious" disorders – the list of the disorders that qualify is managed by the HFEA.

In many other countries the regulatory situation for such procedures is unclear and, like embryo editing, not without controversy. Unless PGD is restricted to a narrow range of disorders, it raises the ethical concern that it may be used – for instance, by private clinics in lax regulatory environments – to screen embryos for other attributes such as intelligence or beauty. Embryos that are not used would need to be either destroyed or donated to science – a practice which is opposed by many, including several religious institutions.

Legality of PGD in selected countries around the world



Source: BioPolicyWiki, EIU

2. The big game: Detecting, preventing and treating common diseases

Common diseases, such as cancer, diabetes, Alzheimer's, and heart disease, are also caused by a failure of our genes to do what they are "supposed" to do. However, unlike monogenic disorders, these diseases are complex and cannot be neatly linked back to individual gene mutations.

Cancer occurs when gene mutations cause cells to grow in an abnormal and anarchic way, giving rise to tumours. Many gene mutations are typically needed for a cancer to develop, and the exact role played by each mutation is still unclear in many cases. For some cancers, such as breast cancer, *inherited* gene mutations (ie, those passed on from parent to child) can greatly increase a patient's risk.

However, overall, *inherited* gene mutations cause less than 10% of all cancers.[10] For other cancers, *acquired* mutations play a bigger role. Acquired mutations occur when a patient's genes become damaged throughout their life, for instance by smoking, exposure to ultraviolet (UV) radiation, or simply as a result of getting older. This interaction between a person's genes and their environment (known as "epigenetics") is critical to understanding how diseases like cancer occur, and is the subject of considerable research today. These environmental factors could be personal choices, such as diet, exercise and lifestyle, or external factors, such as clean water and air quality.

The research being carried out could transform how we treat common diseases such as cancer. The starting point will be a better understanding of how the diseases develop, followed by a more accurate identification of at-risk groups, enhanced preventative measures, and more targeted treatment plans.

Earlier identification of those at risk

Genome-wide-association studies (GWAS) compare the genetic variation of healthy individuals with that of those afflicted by common diseases such as cancer and Alzheimer's. If these studies can access a sufficient number of genomes, this could allow researchers to draw a statistical link between the presence of different gene mutations and the probability of developing the disease in question.

This would enable healthcare providers to identify people at risk. For instance, approximately 60% of women with a harmful BRCA1 mutation will develop breast cancer in their lifetime (compared with 12% of women without the mutation). For ovarian cancer, the risk for a mutation carrier is 39%, compared with just 1.9% for the rest of the population.[11]

Associations between genes and common diseases

Disease	Eczema	Autism	Heart Disease	Alzheimer's
Study	In 2012, researchers identified 10 new gene variations associated with eczema, on top of 21 that had been identified previously.	In 2012, researchers identified 65 genes that contribute to autism, including 28 with a "very high confidence" level.	In 2014, scientists at UCL discovered a gene variant (APOC3) in healthy trial participants that was associated with a lower risk of heart disease.	In 2013, research backed by the Cure Alzheimer's Fund uncovered 12 new gene variations connected to early-onset Alzheimer's disease.
Source	Nature Genetics Journal, 2012	Molecular Autism Journal, 2012	University College London (UCL), 2015	Journal of Molecular Psychiatry, 2013

Source: EIU

Prevention better than cure

As the case of Angelina Jolie showed, there are preventative measures that people at risk can take.[12] After discovering that she had a mutation in BRCA1 gene, Ms Jolie underwent a double mastectomy, and two years later she elected to have her ovaries and fallopian tubes removed.

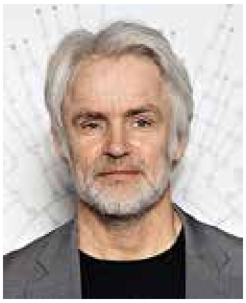
However, the decision to undergo such invasive surgery should not be taken lightly and in many cases would be unwise. Mastectomies can have a substantial psychological impact, while the removal of ovaries and fallopian tubes triggers a "surgical menopause", with various side effects. Only 1% of women have a BRCA mutation, so many will not be at risk. Family history is also important. Ms Jolie's level of risk was substantially higher than that of many other women because both her mother and grandmother succumbed to ovarian cancer.

The quality of screening and treatment for the disease in question also needs to be considered. Breast cancer is often detected early because there are effective screening tools available, such as mammograms. By contrast, ovarian cancer is often not detected until it is too late since screening is unreliable and symptoms (such as stomach pain and weight gain) are common and often attributed to other causes. As a result, almost 90% of the more than 230,000 women diagnosed with breast cancer in the US every year will be alive five years later. By contrast, of the more than 21,000 women who are diagnosed with ovarian cancer every year, more than 50% will die within five years.[13]

The difficulty of such decisions has led to a growing need for "genetic counsellors" who typically specialise in both medical genetics and counselling. They advise patients on their predisposition to developing diseases and the most appropriate course of action. They do so by assessing a patient's genomic data, but also other factors, such as their medical history and family history. This allows for more nuanced consideration of the options and helps patients avoid making hasty decisions.

In many cases, a combination of enhanced screening and behavioural changes (such as an adapted diet) will be the most appropriate preventative approach. As highlighted by Dr Kári Stefánsson, a prominent neurologist and CEO of Icelandic biopharmaceutical company DeCODE, in an interview with the EIU, having gene mutations may become similar to having high cholesterol – ie, it is something that increases the chances of developing a disease, but it is also something that can be tracked and managed (for instance, through a healthier diet and more physical activity).

"Gene mutations may become similar to (having high cholesterol) - something that can increase your chance of getting a disease, but something that can be tracked and managed."
- Dr Kári Stefánsson, CEO, DeCODE.



Personalising the treatment approach

In time, the preventative approaches outlined above may help to decrease the prevalence of common conditions like cancer. However, they are unlikely to be completely eradicated anytime soon. Fortunately, an individual's genomic data can also be used to develop effective treatments.

Drugs are often prescribed according to what is expected to work best for the average patient (based on evidence from clinical trials that typically cover the population as a whole). However, whether a drug has its desired effect often depends on that patient's genetic profile. This means that some drugs work better for some patients than for others. Certain drugs may also cause side effects for some patients, but not for others.

Based on new genomic data, drug companies can develop medications geared towards those with specific genetic profiles. For instance, the breast cancer drug Trastuzumab works only for women whose tumours are caused by a particular gene mutation. Similarly, many promising drugs that did not pass clinical trials may be viable treatments, but only for those with a certain genetic profile (see case study, below).

As our understanding of genetic mutations in common diseases continues to grow, the hope is that drug companies will develop new, more effective treatments tailored to the mutations in question. This combination of pharmacology and genomics is known as pharmacogenomics, and allows for the "personalisation" of a patient's treatment.

Case study: The search for a viable alternative to chemotherapy

Chemotherapy uses chemicals to kill cells and is often used alongside radiation therapy and surgery to treat cancer. Although it has helped countless people to live longer lives, it can be a brutal treatment and many live in hope that new drugs can be developed that offer viable alternatives.

Certain types of lung cancer are associated with mutations in the EGFR gene (Epidermal Growth Factor Receptor). In response, AstraZeneca developed an EGFR-inhibitor drug, known as Iressa, to target cells carrying the mutation. The researchers demonstrated through clinical trials that the medication can lead to longer progression-free survival and better quality of life compared with conventional chemotherapy.[14]

The US Food & Drug Administration (FDA) approved Iressa for use in the US in 2003. However, the drug was initially administered to all patients regardless of whether they had the EGFR mutation. As a result, its efficacy was limited and the FDA later withdrew it from the market. However, in June 2015, the FDA re-approved it, after new evidence showed that it was effective, but only for patients with the EGFR mutation.[15] It was approved only for patients with the mutation, and an accompanying diagnostic kit was approved to identify suitable patients.

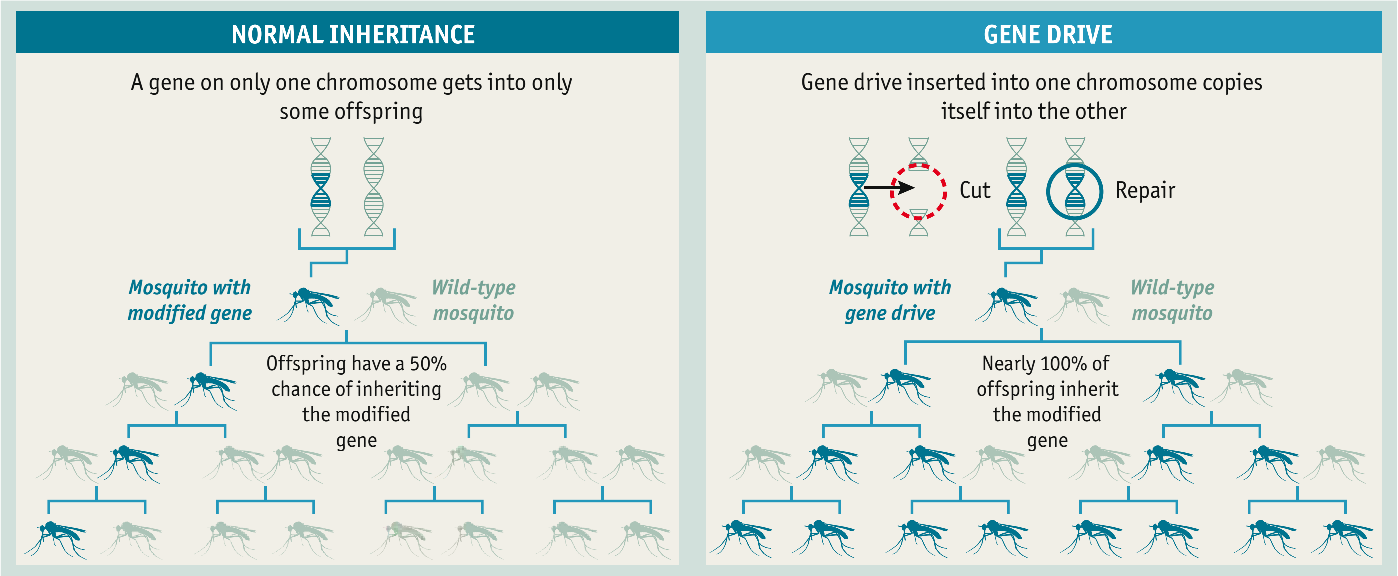
3. Thinking outside the box: Gene drives and next-gen transplants

The examples above outline ways that healthcare practitioners can use patients' genomic data to diagnose, treat and prevent diseases – both rare and common. However, the development of the CRISPR-Cas9 technology, and the more precise type of gene editing it allows, has prompted a debate on mechanisms to improve human health in ways that would have seemed outlandish just a few years ago. Of particular note are "gene drives" and "next-gen transplants".

Gene drives: An end to malaria?

Gene drives edit a specific gene mutation into a plant or animal. They are designed to spread rapidly throughout the full population. In April 2015 biologists Ethan Bier and Valentino Gantz successfully used CRISPR-Cas9 to edit the genes of a fruit fly. The modified gene was inserted on both chromosomes, so that when the fly breeds, it passes the modified gene on to practically its entire offspring, thus "driving" it through the population.[16]

How a gene drive works



Sources: Scientific American, Nature, The Economist, EIU

Dr George Church, a prominent researcher at Harvard Medical School, has been examining the possibility of using gene drives in mosquito populations so as to render them resistant to the parasite that causes malaria. If such mosquitoes were to rapidly breed throughout the population, they could usher in the end of the disease.[17]

However, Dr Church and his colleagues have also highlighted challenges that may arise. The modified mosquitoes might interact differently in the natural environment, which could have unintended consequences for ecosystems. There are 3,500 named species of mosquito, of which only a few hundred bite humans. Some argue that inadvertently wiping out a species of mosquito could leave birds and fish without food, or plants without a pollinator. Other scientists argue that the ecosystem impact would be minimal and, on balance, positive.

The speed at which CRISPR-Cas9 is being refined means these challenges will need to be addressed quickly rather than in the long term. In August 2015, the US National Academy of Sciences initiated a wide-ranging review of gene drives, with many scientists calling for strict conditions and safeguards for all experiments. Another mooted response is for scientists to simultaneously develop ways to reverse the gene drives, if needed.

Next-gen transplants: Is the world ready for pig hearts?

Every day, organ transplants save lives. However, rates of organ donation remain low in many countries and some traditional sources (such as fatal road accidents) are diminishing. As a result, thousands on waiting lists die each year.

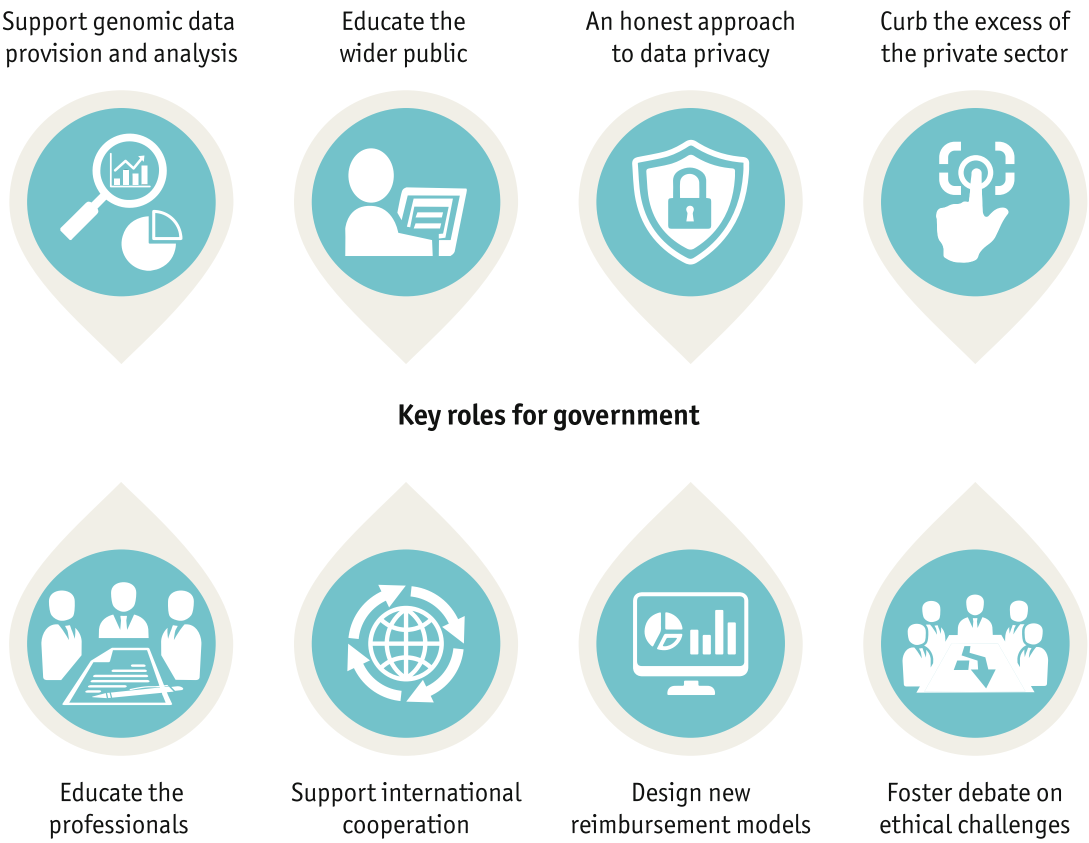
The idea of transplanting animal organs into humans has existed for some time. In 1984 an American child lived for three weeks after receiving a baboon heart that was intended as a stop gap until a human heart could be found (the child ultimately passed away).

The main risk of animal–human transplants is disease inheritance. For instance, the DNA of pigs, often seen as the best candidates for human transplants, carries viral genes that would infect human cells. However, in an experiment in October 2015, Harvard's Dr Church and his colleagues used CRISPR-Cas9 to successfully "snip out" the DNA sequences that carry the viral genes. While not giving the green light for such operations to take place, the experiment did suggest the disease inheritance obstacle could be overcome.

How should governments respond?

Much of genomic medicine is relatively uncontroversial and offers a clear way to enhance, rather than replace, the traditional healthcare model of prevention, diagnosis and treatment. However, it does raise technical and ethical challenges relevant to governments. As a result, the public sector needs to work with scientists, the private sector, and civil society to support the development of genomic medicine, while also managing its implications.

Key roles for government



Source: EIU

1. Support genomic data provision and analysis

The impact of genomic medicine hinges on being able to access and research genomic data from large numbers of people around the world, along with supporting data on their medical history, family history, and diet. However, these datasets are vast – an individual genome alone contains more than three billion basic blocks, or "letters". This deluge of data is leading to "bottlenecks in almost all areas of genomic research", according to Dr Eric Green at the National Human Genome Research Institute (NHGRI).[18]

With this in mind, machine learning and artificial intelligence (AI) hold considerable promise (see chapter 1). Dr Jun Wang, founder of the Beijing Genomics Institute (BGI), and one of China's most famous scientists, recently left the BGI to set up a new AI initiative. It will draw on advances in computer processing power, cloud computing, and AI algorithm design to uncover insights into the relationship between genes, lifestyles, and environmental factors so that diseases can be more accurately predicted.

"(The deluge of genomic data) is leading to bottlenecks in almost all areas of genomic research"
Dr. Eric Green, National Human Genome Research Institute (NHGRI).

According to Dr Wang, the technical aspects are largely in place, or are coming, but the big debate is about how to access individuals' data. One approach would be to integrate patients' genomic data into their electronic health records (EHRs), where it would sit alongside data on their medical history, as well as data from new sources (such as mobile apps). Patients would agree to make this data available to government-backed research institutions, with clear provisions on how it can be used (with monitoring being carried out by a centralised regulatory agency). In exchange, citizens would receive an enshrined right to universal healthcare – the quality of which will continue to be enhanced by the data they provide. In effect, this system would serve as a grand bargain between state and citizen.

2. Educate the wider public

The system outlined above assumes that people can be persuaded to hand over their data to governments. However, perceptions of genomics are often shaped by history and imagination. Some people associate it with past eugenics movements and talk of "designer babies", rather than practical improvements in their own health.

A government-backed education programme could be launched to support citizen involvement in the "grand bargain" outlined above. General practitioners and genetic counsellors could start by explaining to patients what their genomic data can do, and what it cannot do. This could be supplemented with wider public education initiatives, focused on certain target groups (such as young women with a family history of breast cancer).

3. Adopt an honest and clear approach to data privacy

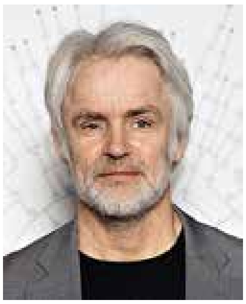
No type of data is more personal than an individual's DNA. In the current climate, when questions about data privacy are more prevalent than ever, this raises a key challenge to developing the system outlined above. Governments need to obtain explicit consent from citizens but also provide clear explanations about how their data will be used.

Those collecting data also have a duty not to over-promise. In today's cyber-driven world, nobody can offer a 100% guarantee that a data breach will not occur. What governments can do is to reassure citizens that their genomic data will not be used by the private sector to discriminate against them (see below).

4. Curb the excess of the private sector

A group of leading scientists interviewed by the Economist Intelligence Unit stressed that the private sector has played a major role in advancing genomic medicine – particularly in next-gen sequencing technology and new treatments. This must continue if the potential is to be realised.

However, there will always be those who seek nefarious gain. One worry is that people's genomic data, or their gene mutations, could be used against them. Employers may avoid hiring a candidate they fear will develop an illness. Insurance companies might refuse to insure those who carry certain gene mutations (or offer lower premiums to those who do not).



"Concerns about the misuse of genomic data can be addressed by government regulations prohibiting genetic discrimination."
- Dr Kári Stefánsson, CEO, DeCODE.

As pointed out by Dr Kári Stefánsson, such concerns can be addressed by government supervision and regulation. The US has already taken action to do this. In 2008, it passed the Genetic Information Nondiscrimination Act (GINA) which prohibits the use of genetic information by insurers and employers.

Similar supervision and regulation is needed for direct-to-consumer firms that offer to sequence a person's genome and advise them on how to manage their disease risks. In October 2013, the US FDA prohibited 23andMe from providing any health information to its customers, as it was worried that they might incorrectly diagnose themselves with diseases they didn't have. In October 2015, the FDA re-approved the company, but for a narrower range of services. It had initially offered consumers information on their risks of developing various diseases; now it will be limited (for the time being) to providing reports on whether customers have specific genetic mutations that could lead to a disease in their offspring.

5. Educate the professionals

Primary care physicians will need to play a frontline role in obtaining patients' genomic data and then using the latest research findings to enhance their diagnosis and treatment. However, many of these professionals will not have come across genomics in their undergraduate courses, given its relative novelty. Initiatives like the Genomics Education Programme (GEP), set up by the UK's National Health Service (NHS), aim to fill this void through a series of self-directed courses for staff on topics such as "consent and ethics".

According to Dr Bobby Gaspar, another bottleneck is the lack of bioinformaticians, who use cross-disciplinary skills in computer science, statistics and engineering to interpret genomic data. Similarly, the number of programmes to train genetic counsellors, who advise physicians and patients on how to use genomic data, needs to be ramped up. The US Department of Labor's Bureau of Labor Statistics predicts that employment of genetic counsellors will grow by 41% between 2012 and 2022.[19]

6. Support international cooperation, rather than competition

When it comes to pursuing advanced science, some argue that international competition can fuel progress – similar to an arms race. However, while acknowledging that a "little competition" can help, in an interview with the Economist Intelligence Unit, Dr Eric Green claimed that robust international cooperation is more important.

First, government research funding is flat in many countries and so pooling resources can help. Second, the nature of genomic data will often necessitate a move beyond national borders. As pointed out by Karen Aiach, CEO of Lysogene, when it comes to developing new drugs for orphan diseases, with small numbers of patients, clinical trials often need participants from several countries. However, governments typically have different safety procedures and rules for such trials, thereby adding to the cost and time of developing new drugs.

> "Governments typically have different safety procedures and rules for clinical trials, adding to the cost and time of developing new drugs. "
> - Karen Aiach, CEO of Lysogene

To support cooperation, governments can work on common standards for trials, as well as for data sharing and IP. They can also provide funding grants that require multi-country involvement and can help facilitate visas for researchers, practitioners and even patients. According to Dr George Church, a useful model to follow is that of the European Organization for Nuclear Research (CERN). Located on the Franco-Swiss border, the centre brings together more than 10,000 scientists, both on-site and virtually. It has 22 member states and has spearheaded key discoveries, such as the Higgs boson particle in 2012.

7. Design new reimbursement models

While the cost of genome sequencing has fallen dramatically, the cost of developing new treatments and drugs may be prohibitive. This is because new treatments will often be targeted at a relatively small number of people, such as those affected by a rare disorder or those with a specific genetic profile. However, the cost and complexity of the drug-development process is similar regardless of whether there are ten prospective patients or 10,000. As pointed out by Aiach, the incentive for private companies to invest in developing new treatments will be driven by their expectations of high prices paid by governments and insurers.

At the same time, essential drugs that are life-saving need to be affordable for health systems. In times of fiscal strain, will governments be happy to foot the bill? How to agree on a price for curing a disease, where previously a lifetime of medical care was required? What range of disorders and treatments should be reimbursed, and to what extent? Should genome sequencing, preventative surgery, and adapted forms of IVF be reimbursed? How do their benefits compare with those of other treatments? These are all questions that governments and health economists need to grapple with.

8. Foster debate on ethical challenges

If an adapted form of IVF can stop a child developing a debilitating disorder, but will also lead to embryos being destroyed, should it be allowed? Should a child be required to give consent, or assent, before undergoing gene therapy? If somebody is found to possess a genetic mutation, should they be required to tell their relatives so they can be screened too?

Many of the ethical debates surrounding genomic medicine have no clear answer. Viewpoints will differ across countries due to culture, religion and history. They will also differ within countries – many of those who have been affected by disorders become ambassadors for pushing the science forward. While these bioethical debates are difficult, they need to be encouraged, both domestically and internationally. In December 2015, a three-day International Summit on Human Gene Editing was held in Washington DC. It brought together hundreds of scientists and ethicists from around the world to debate where the ethical boundaries should lie.

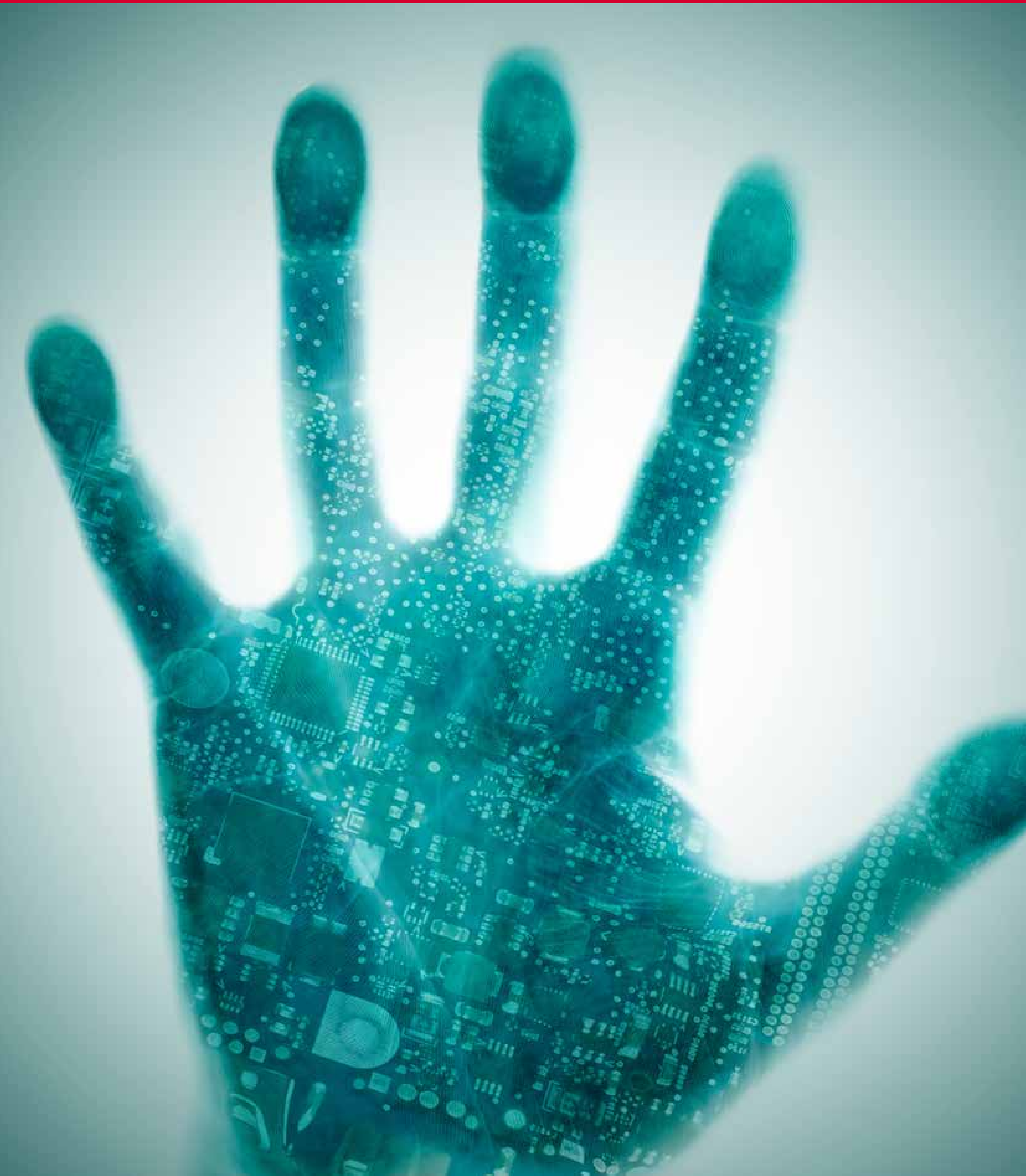
Setting up bioethical institutions, such as the Johns Hopkins Berman Institute of Bioethics or the Hastings Center in the US, is also key. These institutions tackle knotty questions such as: can research on the genetics of intelligence be trustworthy? Over time, such debates can lead to frameworks that guide both clinicians and citizens.

Conclusion

The huge fall in the costs of sequencing a human genome and the rise of new, more sophisticated, gene-editing technologies represent a game-changer for genomic medicine. While discussions in the media often focus on fears about designer babies, much of genomic medicine simply involves a better, more personalised, way to deliver traditional healthcare. This will have implications for how we identify patients at risk of disease, how we prevent and treat those diseases, and in some cases how we eradicate diseases altogether. In the longer term, uses that would have seemed outlandish just a few years – such as organ transplants from animals – may well come on stream.

The challenge for governments is that the same technology and knowledge that brings such benefits to life could potentially be used in other, more nefarious, ways. This highlights the need for government supervision and regulation, in partnership with leading scientists, ethicists, and the private sector. However, it is also crucial that such challenges are not used to forestall progress on the non-controversial aspects of genomic medicine, many of which can be applied today, in a safe manner, with substantial benefits for citizens.

Chapter 3: Biometrics



Executive Summary

A biometric is a unique physical and behavioural trait, like a fingerprint, iris, or signature. Unique to every person, and collectable through scanning technologies, biometrics are incredibly valuable pieces of information giving every person a unique identification which can be used for everything from authorising mobile bank payments to quickly locating medical records after an accident or emergency.

Humans have used biometrics of various kinds for hundreds of years, with some records suggesting fingerprint-based identification in the Babylonian era of 500 B.C. But their true scale is only now being realised, thanks to rapid developments in technology, and a growing need for a more secure and efficient way of identifying individuals.

This chapter describes the power and potential of biometrics, and their potential impact on government services. From a landmark national identification initiative in India to border control in Singapore, the US and the Netherlands, the chapter explores applications of biometrics across continents, spanning digital government services, healthcare, education, welfare, border control, justice, elections, public administration, and policing. It concludes by evaluating the lessons learned from these experiments, and the main takeaways for governments, including privacy rules, the risk of "mission creep", data security, public trust and sustainability.

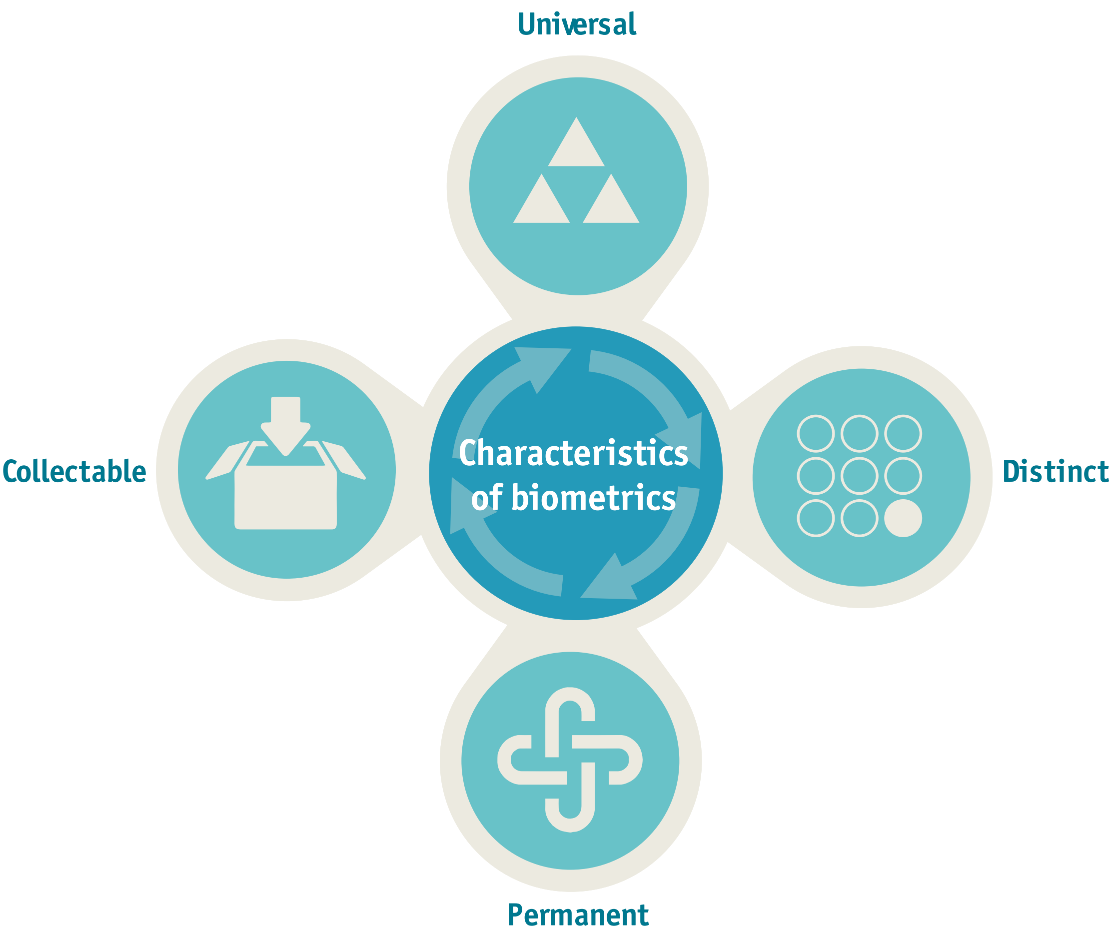
Background

In 2008, India launched a landmark programme to provide unique biometric ID to a population of over a billion people. Aadhaar[1] was the world's largest such initiative, showcasing the scale of biometric technologies, even in a developing-economy setting. Four years later, Apple's iPhone became the first mass consumer phone that could be unlocked through a person's fingerprints. It was the "largest single deployment of biometric sensors ever, and meant that people began to use biometric technology every day rather than once or twice a year at the airport," says Richard Guest, Senior Lecturer of Engineering and Digital Arts at the University of Kent. Biometrics Research Group forecast that 650m people would be using biometrics on mobile devices by the end of 2015.[2] Along with consumer goods and services, biometrics is also entering government services: border security, welfare payments, and even attendance-monitoring at schools and hospitals are among the areas in which biometrics is now deployed in public-sector operations. But its benefits must be balanced against risks and unintended consequences.

What is biometrics?

A biometric is a physical or behavioural trait – like fingerprints, irises, or keystroke patterns – which verifies a person's identity. Any biological or behavioural trait is a biometric, provided that it is universal (every person has it), distinct (people "demonstrate" it differently), permanent (it doesn't change over time), and collectable (it can be measured).

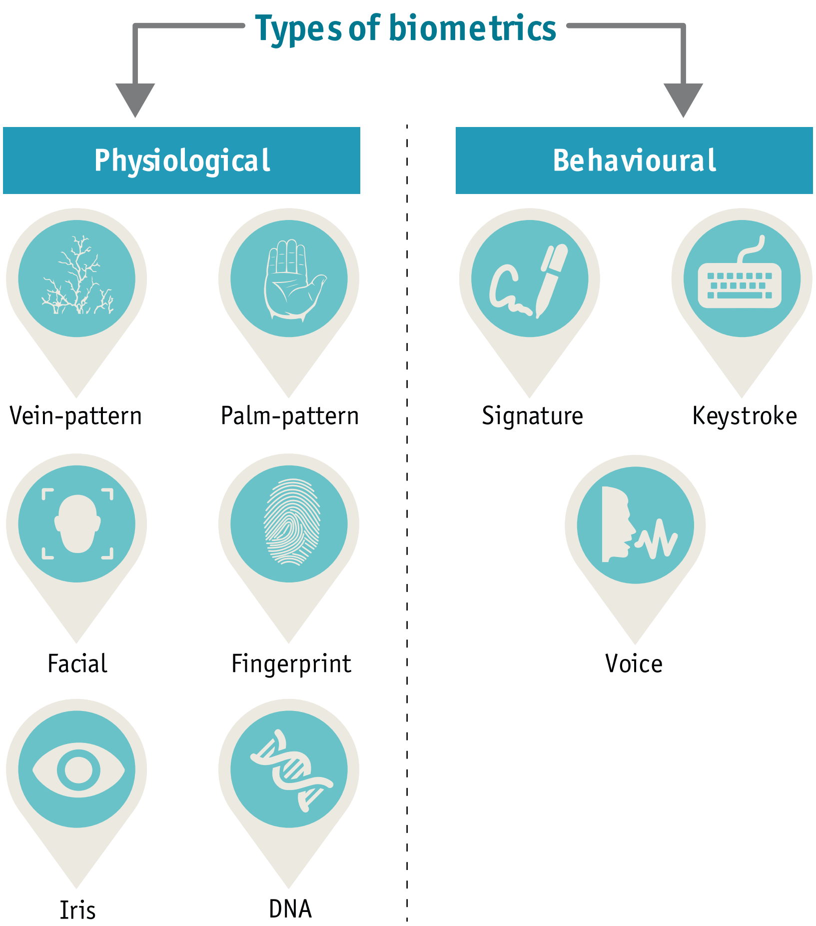
Key characteristics of biometrics



Source: EIU

The most common biometrics are fingerprints, irises, and faces. Less common ones include signatures and keystroke recognition, where a person's movements and behaviours, rather than their biological features, are analysed. Signature recognition assesses the signature's appearance, but also the person's movement as they write it. The person uses a stylus on a pressure-sensitive tablet which tracks how the hand moves; how long it takes the person to sign; the pressure applied; the speed of the hand movement; the overall size of the signature; and the quantity and directions of the strokes. Although signatures can be forged, it is difficult to duplicate all these behavioural characteristics. Keystroke analysis is another widely used behavioural biometric. When a person is typing on a keyboard, a scanner measures two variables: the amount of time a person holds down a particular key ("dwell time"), and the amount of time it takes fingers to move between keys ("flight time").

Types of biometrics



Sources: EIU, Bio-metrica

The strengths and weaknesses of different types of biometrics

FACIAL RECOGNITION

Pros: Easy to deploy through CCTV and facial recognition software
Cons: Accuracy impacted by lighting or facial distortions such as glasses, facial hair, or face coverings

VOICE RECOGNITION

Pros: Non-intrusive, low chance of a false match
Cons: Vulnerable to background noise

FINGERPRINT

Pros: Quick, efficient and accurate - likelihood of mistaken identity is at most 1 in 250,000
Cons: No universal standards exist, fingerprints can change due to occupation, sensors carry a lot of bacteria

IRIS

Pros: High accuracy and time-efficient to deploy
Cons: More invasive, could project health risks, not left as evidence at a crime scene

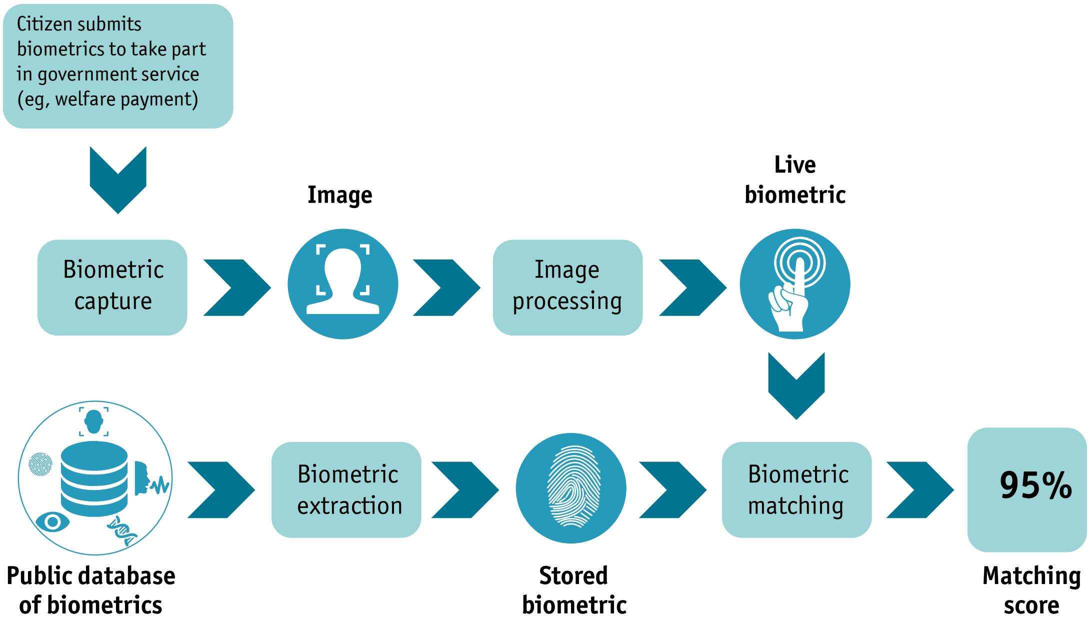
RETINA

Pros: Low error rate
Cons: Expensive, cataracts and asitgmatism create problems

Source: EIU, HP Input Output, TechRepublic

Biometrics can be stored in raw form – such as a facial image on a database – or processed into data. For instance, "iris-recognition" programmes can use the power of artificial intelligence (see chapter 1) to recognise the unique contours of an iris, and save the information in a binary form – ie, as a series of "ones and zeroes".[3] Traditionally, citizens prove their identity by entering a password or PIN (personal identification number), at an ATM or bank, for example. This PIN or password is either right or wrong. In contrast, biometric identification is *probabilistic* – ie, it "guesses" whether a person is who they say they are, based on probability.

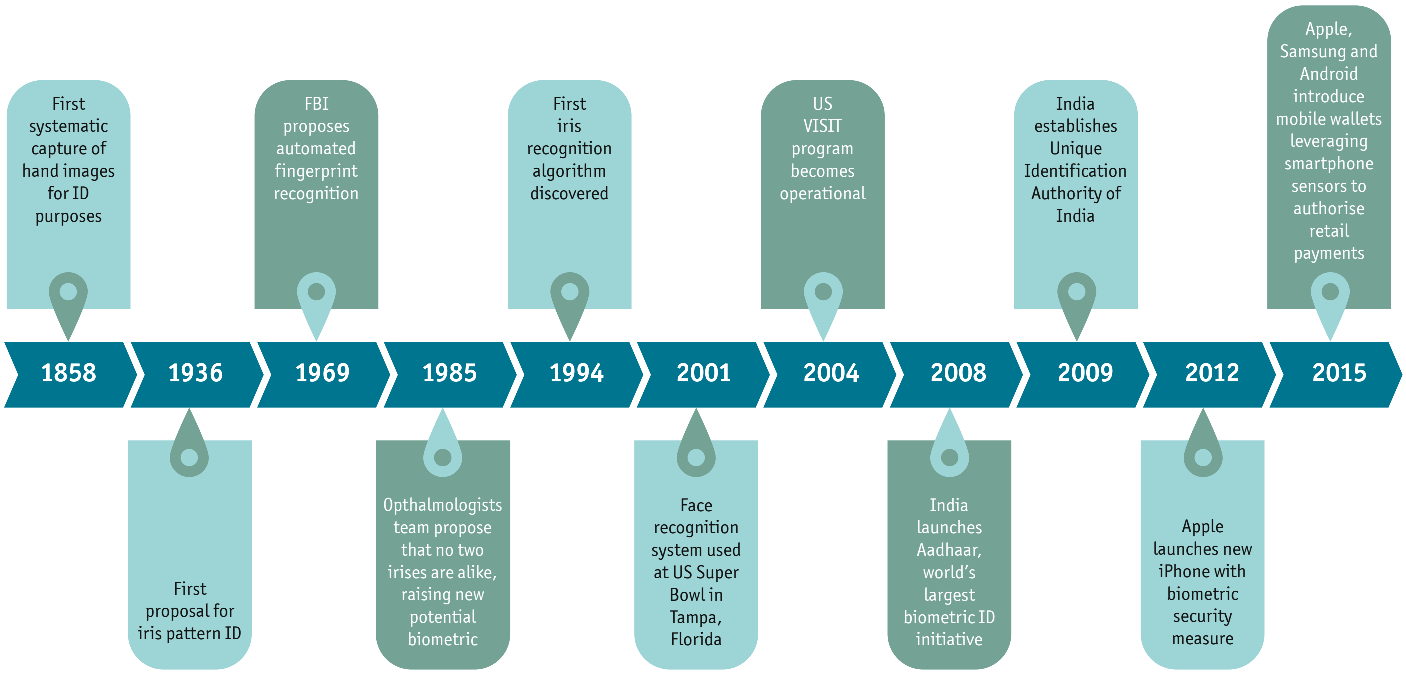
The biometric extraction process



Sources: EIU, Smart Card Alliance

Probability is worked out by picking a threshold between two extremes – the "false acceptance" rate and "false rejection" rate. These are the parameters which determine if a biometric reading successfully identifies a person. False acceptance means that biometric readings (eg, fingerprints) from two individuals are wrongly identified as being from the same individual. False rejection means two measurements from one person are (wrongly) thought to be from two different people (thus resulting in the person being told they have failed to verify their identity). In order for a biometric tool to make a decision on the above, a threshold needs to be set – ie, what percentage probability determines that a fingerprint or iris scan is a 'match'. For example, if a fingerprint that is taken is determined to be a 90% likely match, but the threshold is 95%, it will be deemed a non-match (rejected). A lower threshold makes the system more tolerant to mild variations, such as fingerprint bruising, but also causes the false acceptance rate to go up.

Biometrics – A history of discovery



Sources: EIU, The Economist

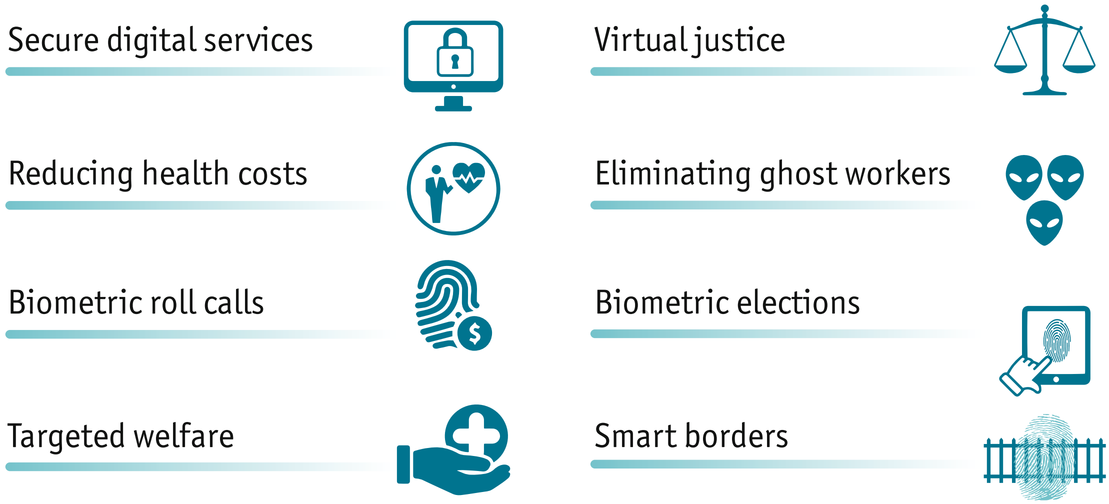
How will biometrics affect government?

The public and private sectors have their own unique reasons for engaging with biometrics. In the private sector, the mobile phone industry – especially Apple and Samsung – have adopted biometrics to enable quick and efficient security for users wanting to access their phones and authorise payments, for instance through the iTunes platform.

Companies tend to have higher rates of "digital" interaction with their "customers" than governments do. People are more likely to shop online on a daily, weekly, or monthly basis, whereas filing taxes or contacting local government may occur only once or twice a year. This frequency of interaction requires ever-stronger security for user payments. Authentications like passwords and PINs have been the dominant security mechanism, but biometrics are increasingly deployed as a more secure option, especially through mobile phone-enabled payment platforms, and new technologies like Apple Pay.

Yet while biometrics is becoming more commonplace in consumer goods like smartphones, it is also being incorporated into the work of governments. Building on its initial use in crime, law enforcement and border control, governments are now using biometrics in welfare services, school enrolment, online learning, and even hospital management.

How is biometrics being used by governments?

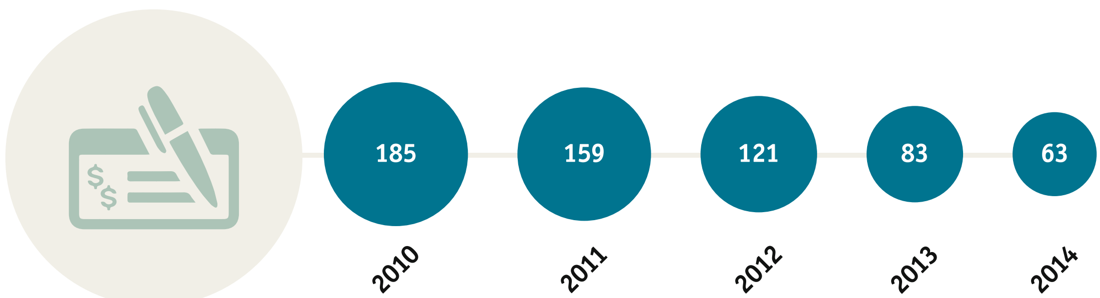


Source: EIU

1. Securing "digital-by-default" government services

Citizens are becoming ever-more accustomed to online transactions. According to Bloomberg, in 2014 one-third of all bank customers in the US had not entered a physical branch in at least six months, and more than 20% had not visited in a year or longer.[4] The Boston Consulting Group estimates that, by 2017, roughly 60% of financial transactions will take place through a mobile device.[5]

Number of paper cheques processed by the US Federal Reserve (million)



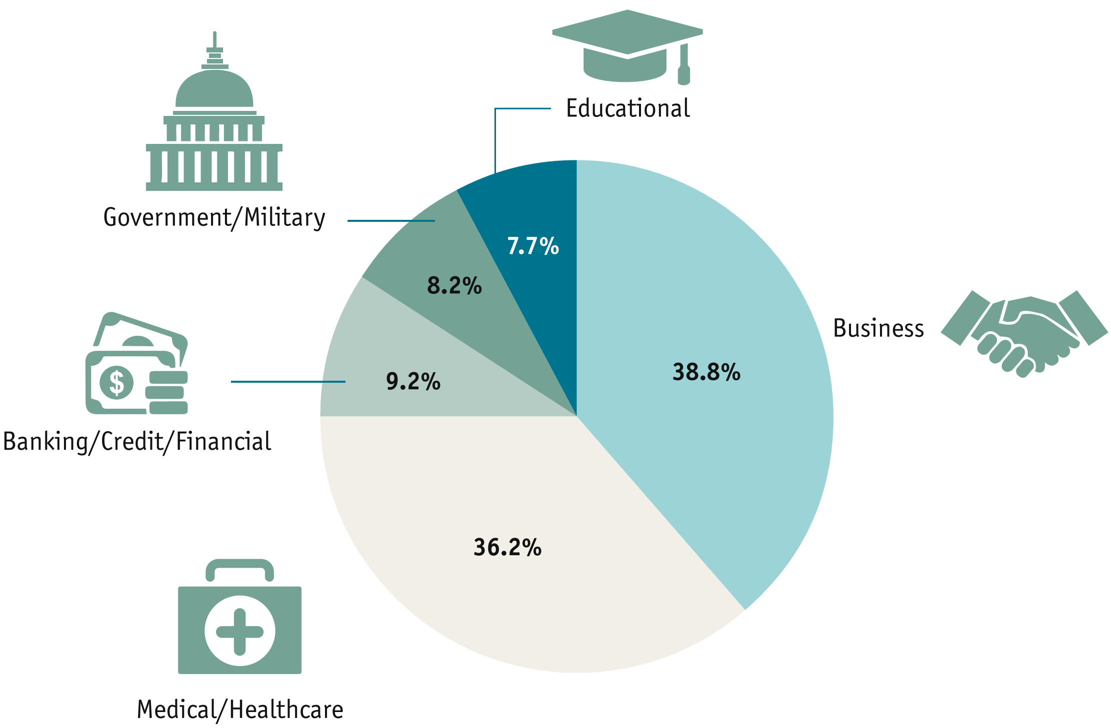
Sources: EIU, US Federal Reserve

As documented in chapter 1, governments now want to emulate such levels of digital uptake for their own transactional services, such as applying for a passport or registering ownership of a property. Although governments have already made some of these services available online, uptake is often lower than in the private sector.

To drive uptake, governments are introducing *digital-by-default* schemes. The goal is to design new digital services that are so convenient to use that anybody who is able to use them will do so. The UK government estimates that this will save it £1.7bn (US$2.63bn) per year.[6] However, if citizens and businesses consume more services online, and make more payments online (such as fines or charges), the risk of fraud increases. If a criminal obtains biographical information about a citizen, they could pass an online verification process and fraudulently use the person's credit card to make payments, or even to apply for a new credit card. The risk is significant because a person's government account tends to have a large quantity of detailed personal and biographical information stored in one place.

Passwords, the common approach to online security, are not enough to stop the problem. As more transactions take place online, people are forced to invent, remember and update increasingly complex passwords. Passwords must be sufficiently random and complex to withstand hacking attempts, but easy enough for users to remember. Individuals often choose one standard password across platforms. If that password is stolen they are vulnerable to many types of theft. The Consumer Sentinel Network, an organisation that compiles consumer complaint data for the US Federal Trade Commission, recorded a 17% increase in the number of identity theft claims between 2009 and 2014, and identity fraud is now the most common customer complaint that is referred to law enforcement.[7]

Data breaches by industry, 2015

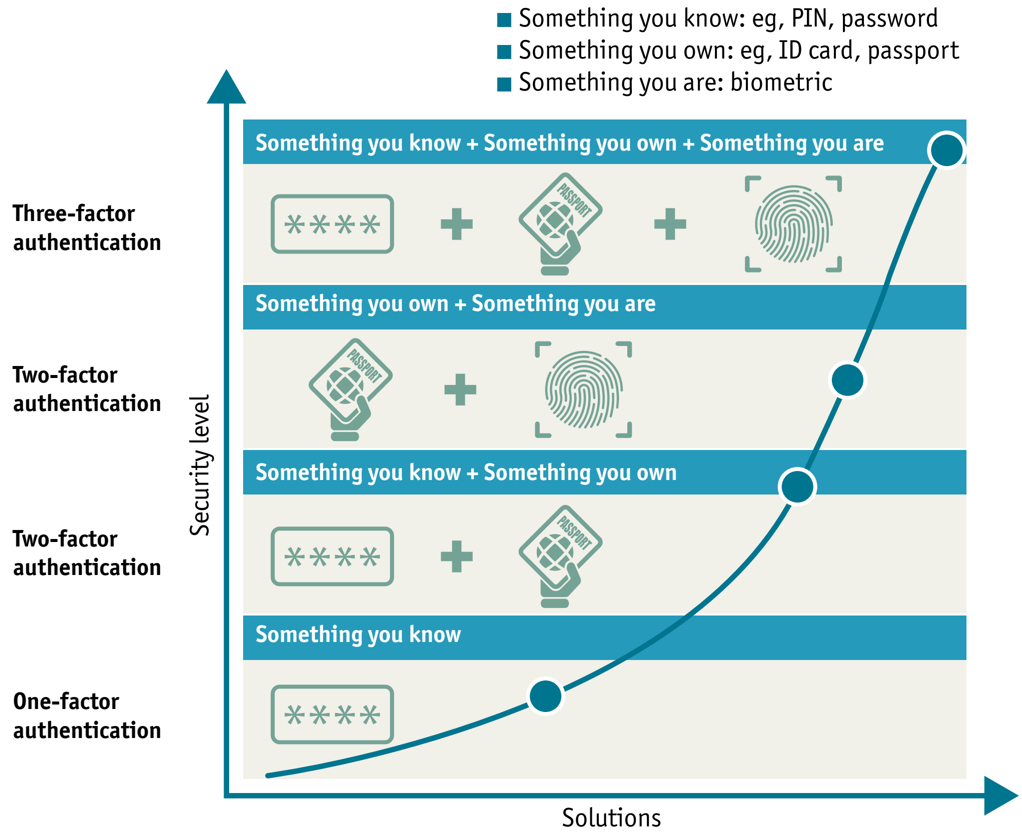


Sources: EIU, Identity Theft Resource Center

Biometrics may provide a safeguard in that it is more secure for authentication than passwords or PINs, which can be guessed or hacked. It is also more secure than more traditional forms of identification. “Many interactions between citizens and government, such as claiming welfare and paying taxes, require verification of a citizen’s identity through traditional means like a driver’s licence or a birth certificate,” says Dr Edgar Whitley, associate professor in Information Systems at the London School of Economics. As Whitley explains, “traditional forms of identification can be faked, especially in less developed countries where new security measures like holographic images or security chips have not been incorporated into traditional ID.”

“Traditional forms of identification can be faked, especially in less developed countries where new security measures have not been incorporated into traditional ID.” - Edgar Whitley, Associate Professor in Information Systems at the London School of Economics

Different tiers of authentication



Source: Smart Card Alliance

Biometrics is far safer, since fingerprint and iris scanning are logistically and technologically more difficult to fake than a photographic ID. Traditionally, iris- or fingerprint-scanning technologies were prohibitively expensive. Today, however, smartphones, with fingerprint- and iris-recognition functions, can be used. For instance, users could authorise payments through fingerprint-enabled smartphones linked to their debit and credit cards. Voice recognition can also be used since it requires little in-home technology, apart from microphones, which are common in today's computers and smartphones.

2. Healthcare: Scanning fingers, saving lives

Healthcare spending is rising around the world as a result of a growing, and ageing, population. Across the OECD, average healthcare expenditure as a percentage of GDP increased from 7.2% in 2000 to 8.9% in 2013. Total health spending in the US is a massive $2.7tn, or 17% of GDP.[8]

As demand for health services increases, cost control becomes paramount. One way to reduce costs is digitisation. Paper-based records are expensive to maintain and prone to errors and incorrect filing (filing one patient's data in the file of another), especially when files are transferred between general practitioners (GPs), hospitals, and specialists. In one prominent case of mistaken twin girls at the Children's Hospital in Denver, it took 16 hospital staff across multiple departments three months to correct the clinical records.

Misidentification can be expensive and potentially catastrophic, especially during emergencies when there is limited time to double-check a patient's record. Mistaking a patient's medical history can result in prescribing the wrong medication, sometimes with fatal consequences. Paper files also make it easier to commit fraud when an individual claims to be someone they are not in order to claim medical benefits or prescriptions that are not theirs.

Transitioning to biometric-enabled digital health records reduces error rates and makes fraud more difficult. If health records contain biometric information, the identity of an unconscious patient, or someone hospitalised abroad, for example, can be established quickly and accurately, allowing healthcare professionals to focus their time and attention on treatment.

Hospital management can also be improved, as biometrics can be used to monitor staff attendance in hospitals. Patients and doctors can use their fingerprints to "check in", and hospitals can use this real-time information to identify inefficiencies in their operations – for instance, matching peak demand with staff supply. Biometric systems have already been implemented to cut down on doctor absenteeism, notably in India, using the equivalent of a "punch card" – ie, when an employee enters the hospital they "check in" using their fingerprint or palm.

In 2012, the *India Times* noted that all senior staff at Indian hospitals and medical colleges would have to use fingerprints to check in in the future.[10] Media reports show that Madras Medical College, one of the largest teaching hospitals in Chennai, has seen fingerprint registration rates of 90%,[11] while smaller hospitals in the city have seen implementation stall. In 2012, the Directorate of Health Services Director Dr N. V. Kamat announced that biometric fingerprint readers will be installed at 98 dispensaries (for the most part located in rural areas) to cut down on absenteeism and improve the quality of service provided to patients.[12]

3. Education: The end of school "roll call"?

Some primary and secondary schools in Europe and the US are looking to biometrics to make their day-to-day operations more efficient. A number of public schools in Sweden, the US, the UK and Germany now use fingerprint scanners to control student access to lunch funds, library books and computers, and to monitor attendance.[13]

Biometrics is also being explored at the tertiary level. Universities are seeking to increase revenue, especially in countries like the UK and US where public funding has fallen. The transition to online teaching – notably to Massive Open Online Courses (MOOCs) – has been identified as one way to expand the student base. According to Class Central, an online MOOC aggregator, the number of MOOCs has risen from almost zero in 2011 to almost 2,500 in 2015, with many elite universities now offering them. However, because MOOCs are online and "unsupervised", cheating is harder to detect. Fraudulent companies have emerged that offer to complete online certificates on behalf of students. In a 2015 study, researchers at the Massachusetts Institute of Technology (MIT) examined the prevalence of a popular cheating technique known as "copying answers using multiple existences online" (CAMEO).[14] Under this approach, a user creates multiple accounts, one of which is the primary account that will ultimately earn the MOOC certificate. The other accounts are used to find or "harvest" the correct answers to assessment questions for the master account. The MIT study found that 1.3% of the certificates in the 69 MOOCs they examined were given to CAMEO users, and among earners of 20 or more certificates, 25% used the CAMEO strategy.[15]

Biometric technology – especially voice recognition – could guard against cheating during assessments by providing a direct link between the student and the exam. Behavioural-based techniques like keystroke analysis could also be employed alongside more traditional techniques like fingerprint verification. The former technique has been used by Coursera, an education technology company, to monitor online attendance which currently sits at just 15%.[16]

4. Targeted welfare programmes

> Biometrics are dramatically improving the efficiency and transparency of welfare payments, subsidies and economic development initiatives in poor countries.

Biometrics is helping to dramatically improve the efficiency and transparency of welfare payments, subsidies and economic development initiatives in poor countries. India's biometric programme, in particular, has focused on improved targeting of welfare.

In several Indian states prior to the Aadhaar initiative, 58% of subsidised grain did not reach recipients due to identification errors, fraud, and theft.[17] To alleviate this, India sought to more accurately identify and authenticate its population using biometrics. To enroll in Aadhaar, a citizen submits a photograph of their face and a scan of all ten fingerprints and both of their irises, and receives a unique 12-digit identification number. These data serve as a reference point to ensure the individual is who they claim to be in future interactions with government.

In a country where hundreds of millions of people had no verifiable form of identity, more than 925m Indians, roughly 75% of the population, enrolled within seven years.[18] Citizens engaged because of the difficulties they face without an identity, which affects everything from registering a property and claiming inheritance to drawing on government benefits. Aadhaar has had a profound impact. One Indian state, Andhra Pradesh, discovered over 6m fraudulent identities and saved $7.6m per month. This more than paid for the $10m implementation cost within just two months.[19]

Biometrics can curtail "subsidy leakage", a problem for countries in which subsidies to poor households are siphoned off. Historically, governments have found it difficult to verify the identity of beneficiaries and rely on local officials as middlemen. But these officials may misreport (usually over-report) demand in order to steal the surplus and sell it on the black market. This leads to subsidy "leakage" via "ghost" beneficiaries.

For example, the Indian government subsidises domestic cooking fuel (liquefied petroleum gas, LPG) but taxes commercial fuel. In 2013-14, roughly 165m households claimed this benefit. But some local officials have been found to be selling surplus LPG to businesses after claiming it for ghost households. In June 2013 the scheme was linked to the Aadhaar database and the subsidy was transferred directly to the target's bank account, which requires biometric verification to access, leading to an 11-14%, or $880m-$1.12bn (2013), reduction in domestic fuel purchases as ghost households evaporated.[20]

Biometrics have played a role in welfare interventions in Sub-Saharan Africa. In Malawi, farmers have long suffered from both a lack of identity and underdeveloped credit markets. In 2009, the World Bank financed a project that separated a group of smallholder Malawi farmers into two groups.[21] In order to receive a loan to buy paprika seeds, half had to provide their fingerprint, which served to link their credit history and their true identity, and the other half did not. The high-risk farmers that had been fingerprinted increased their repayment rate by about 40%.

Biometrics can thus encourage lenders to engage more with low-income or higher-risk customers. Historically, lenders have found it difficult to keep track of those with poor credit histories, and have often limited the supply of credit to those they personally know, or focus on serving only "safe" borrowers – who are also a less 'in need' demographic. Biometrics means borrowers can develop a positive credit history regardless of their income status, while defaulters can be excluded from the system. This helps lenders avoid branding all low- income customers as "high risk", since many are not.

Governments in richer countries are also using biometrics to improve welfare targeting. After the financial crisis of 2008, unemployment increased in the OECD, followed by a rise in welfare benefits. At the same time, many countries saw their budget for social services decrease as they reallocated public finances to fund bailout packages. To ensure that social welfare applicants are not fraudulently receiving support, biometrics has been used to improve identification. The US state of California has used the Statewide Fingerprint Imaging System to verify the identity of welfare recipients and cut down on fraud via "double-dipping" whereby individuals working under one name claim benefits under another.

5. Justice: Hands where I can see them

Biometric technology is already part of the legal process, most obviously through the analysis of fingerprints or DNA traces left at a crime scene or on a victim's body. There are, however, wider applications. Because of the predominance of face-to-face authentication (such as appearance in courts and judicial institutions), many legal processes are time-intensive, paper-oriented, and cumbersome. In the UK, the courts and prosecution services use 160m sheets of paper each year, which is both expensive and a security risk.[22]

Biometric verification could reduce red tape and improve security. For example, police officers could log evidence digitally, such as photos of a crime scene or witness statements, authenticating their identity biometrically rather than attending courts in-person. It is also less likely that a police officer would falsify evidence if they are biometrically linked to its submission, and the time saved by remote submission could allow them to focus on more pressing policing duties.

Facial-recognition software might allow dangerous criminals to appear in court from a holding facility via a video conference, saving resources spent on transporting the individual and reducing the security risk of escape. Scanning a prisoner's iris rather than taking all ten of their fingerprints could avoid the need for officers or guards to take off their handcuff restraints, decreasing the risk of violence and injury. Finally, some victims or witnesses can give evidence via video, avoiding the need to make distressing and time-consuming appearances in person. Their identity could be established through biometric identification tools taken to their home, or to another location if this is deemed appropriate.

6. Eliminating "ghost" workers

The most severe type of government-worker absenteeism is the "ghost" worker phenomenon. This comes in two forms: people who are either on the payroll but do not attend work, or "fictitious" workers who are invented by a member of staff to access their salary and benefits. Less severe than ghost workers, but more common, is simple absenteeism, whereby government workers regularly miss work but are still paid their full salary. Such problems can be mitigated through biometrics. Fingerprints or handprints can be used by government staff to check in and out during the course of the day, allowing governments to monitor attendance and ensure that workers are "real" people.

India has used biometrics to crack down on government staff absenteeism. In November 2009, it was announced that biometric technologies had revealed 22,853 civil servants in Delhi's government who "did not exist", equating to $43m in bogus salaries.[23] In 2014 Narendra Modi's government implemented the Biometric Attendance System (BAS) across Delhi's government departments. The Center for Global Development, a think-tank, notes that on October 7th 2014 there were roughly 50,000 employees within the government, 32,000 of whom were enrolled in the BAS. Of those 32,000, only 25,000 were present at work on that day – an absentee rate of 21%.[24]

Nigeria's government also used biometrics to eliminate 43,000 ghost workers from public-sector payrolls in 2011, saving the government $67m. A similar initiative in Guinea-Bissau has seen 4,000 ghost workers eliminated. There is scope for biometrics to increase savings in other countries.

In Kenya, it is estimated that at least $1m per month is spent on ghost workers.[25] According to Transparency International, Cambodia could be spending between $32m and $43m annually on ghost workers, and in Tanzania that figure is estimated at $76m. In Honduras, ghost workers make up 5.1% of staff in the health sector and 8.3% of GPs.[26]

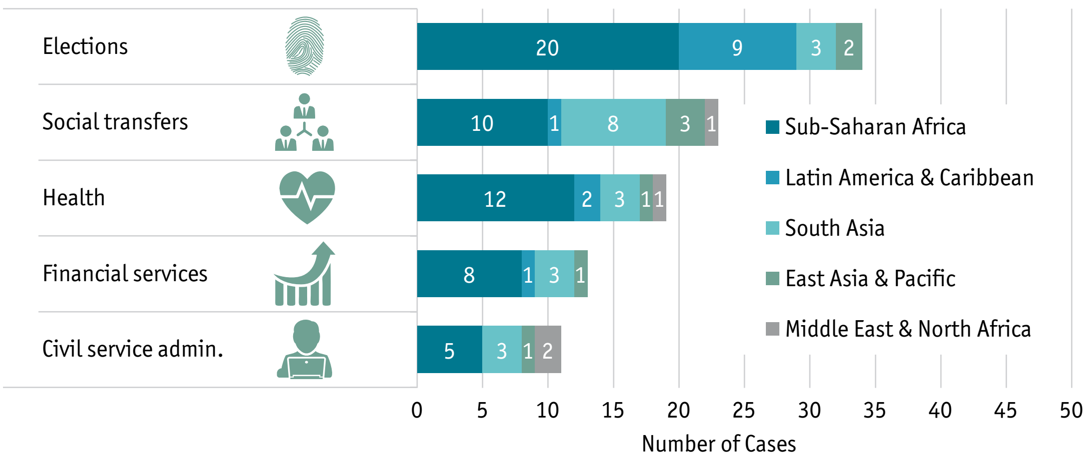
7. The "eyes" have it: Biometric elections

Elections are often open to corruption or allegations of corruption. Numerous civil wars have been sparked by accusations of vote-rigging techniques like ballot box stuffing or electoral roll manipulation. Both are fundamentally problems of identification that could be avoided or minimised through the use of biometrics.

Countries can require voters to verify their identity at the polls through biometric ID cards, a trend spreading throughout countries where election tampering has been common.[27] Such cards, usually plastic, include biometric information stored on an embedded microchip, or on a magnetic strip across the card. To be authenticated, the voter brings their biometric card to be scanned at polling stations (it is logistically easier to scan biometric cards than to take new biometric information such as a fingerprint or iris scan).[28] Countries utilising biometric voter ID cards include Nigeria, Benin, Côte d'Ivoire, and Ghana, but many other sub-Saharan African countries are also implementing the technology.

Although international donors provide funding for about half of all African rollouts, many governments are aware of the benefits that biometric-based identity can bring, whether it be targeted service provision, as India's Aadhaar programme has brought, or to help curtail electoral corruption and prevent the violence that has occasionally been associated with contested elections in the past.

Biometric programmes in developing countries



Sources: EIU, Center for Global Development

8. Smarter borders

After the tragedy of the 2015 Paris attacks, the threat of terrorism is again high on the radar of citizens and governments around the world. The search for anti-terrorism technology has been intensifying for over a decade. According to Richard Guest, "there was a real push after the 9/11 terrorist attacks to find new security solutions, and that coincided with biometric technology reaching a level of sophistication where large-scale public deployment became possible."

"There was a push after the 9/11 terrorist attacks to find new security solutions, and that coincided with biometric technology reaching a level of sophistication".
- Dr Richard Guest, Senior Lecturer in the School of Engineering, University of Kent

Politicians know that while terrorist attacks are rare, the fallout, if governments are perceived to have been complacent, is severe. After 9/11, the US mandated that all non-Americans provide fingerprints upon entry to the country, to be checked against the Department of Homeland Security's Automated Biometric Identification System (US IDENT) database to determine whether they are on a terrorist watch-list.

Most citizens accept the burden, given the seriousness of the threat. James Loudermilk, senior technologist at the FBI's Science and Technology Branch, stated at a London conference in September 2015 that, "The public is comfortable with being biometrically searched, provided [law enforcement] does not miss anyone."

Governments of countries under threat are generally providing the financial support needed. "Members of the US Congress believe that they must always give more money and power to spy agencies because they are afraid of being accused of weakness in the event of a terrorist attack," according to Kade Crockford, director of the American Civil Liberties Union's Technology for Liberty Program.

As well as increasing security, biometrics can reduce the delays caused by tighter border control. As investment in biometrics for border policing increases, it can facilitate the movement of pre-screened individuals and avoid clogged transit systems at airports and borders. The US Global Entry Program links biometric databases between the US and several other countries like Germany, New Zealand, Australia, and South Korea, to screen low-risk travellers and allow for rapid access to the country on arrival.[29]

According to analysis by the US Government Accountability Office, "Global Entry" visitors wait an average of 10-27 minutes less than regular travellers when entering the US.[30] This has produced promising results: entry into the US via Global Entry kiosks nearly doubled between 2012 and 2013, from 1.1m entries to 1.9m.[31] "If these efficiencies continue, biometric technology will continue to be the backbone of border control systems going forward", according to Dr Guest.

Singapore is another technology leader using biometrics for smarter borders. The country is among the wealthiest in Asia. According to EIU data,[32] Singapore's GDP per capita in 2014 was $56,287, compared with $11,307 in Malaysia; $6,020 in Thailand; and $3,508 in Indonesia. As a result, migrants from these countries try to enter Singapore or overstay their visas illegally. To increase security, without jeopardising efficiency, Singapore operates the Immigration Automated Clearance System

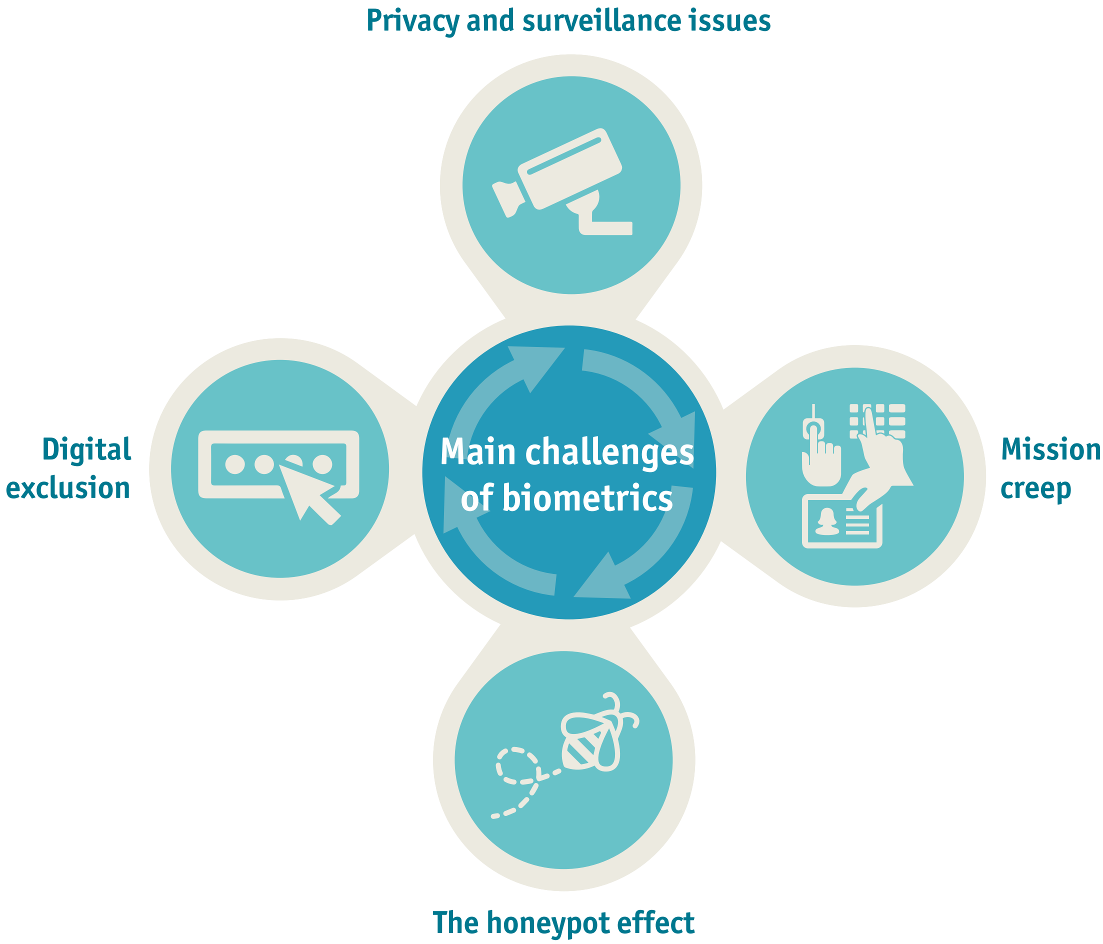
(IACS), a smart card and passport-based immigration system at over 25 entry checkpoint locations around the country, including airports, land-bridge crossings and shipping terminals. "Pre-screened" permanent residents and citizens that have provided their fingerprints and facial images have access to express self-verification terminals, reducing processing times and allowing officials to focus on non-nationals. For everyone else, fingerprint data and facial images are checked against Singapore's internal databases as well as international ones like INTERPOL, the global crime-fighting organisation.

The system is working. The number of illegal entries into Singapore has decreased markedly. In 2014, IACS processed 99m travellers, compared with 65m in 2004. Despite this increase, the number of illegal immigrants and overstayers has fallen sharply. In 2014, 350 illegal immigrants and 1,690 overstayers were arrested, compared with 5,400 and 6,390, respectively, in 2004.[33] Amsterdam's Schiphol Airport is another positive border control case study, with dramatic efficiency gains from its iris recognition system since it became operational in 2006.[34] The airport now processes 60,000 people per day, with an average throughput of just eight seconds, and a rejection rate of less than 1%.

How should governments respond?

Governments wishing to use biometrics will need to make delicate choices about how to collect, use and manage the data. The technology itself may be improving in leaps and bounds, but governments also need rules protecting against misuse, as well as robust troubleshooting to mitigate potential unintended consequences which new-fangled technologies can have. Then there are the cultural, historical, legal, political, economic, and religious contexts to think about with regard to how populations will react to biometric information being gathered about them. While there is no universal blueprint for rolling out biometrics, there are several lessons and principles that can be learned from experiences to date.

Key challenges for governments to manage



Source: EIU

1. Develop clear privacy rules

Most criticisms of biometrics relate to privacy and government surveillance fears. Following the US National Security Agency (NSA) citizen spying saga, as revealed by Edward Snowden, society is more alert to government access to citizen's personal information.

One concern is "passive technology" like facial-recognition software, which is used by law enforcement to scan high-traffic areas for terrorists and other criminals. Although the intention might be noble, the technology treats everyone as a suspect and can lead to surveillance of innocent people and the permanent storing of their information. A prominent example was the US Super Bowl XXXV, where the FBI scanned the faces of attendees entering the stadium without their knowledge, leading to public outcry.

As a result, governments must ensure biometric usage is proportional to the need being considered, factoring in privacy concerns, security risks, costs, effectiveness, benefits, and convenience, and whether there is a non-biometric alternative that achieves the same goals for a lower financial cost or reduced privacy risk.

2. Avoid new forms of racial discrimination

Observers also worry about embedding discriminatory practices. In countries like the US, there has been a long history of "stop and search", in which young black males and other ethnic minorities are overwhelmingly targeted for checking by law-enforcement officers. This in turn leads to large databases dominated by members of these racial groups, leading to a vicious cycle in which they become the primary dataset and the point of focus for law enforcement. This increases the likelihood of these individuals becoming suspects – and potentially being falsely accused – in later cases where they may be a close match to a crime (especially when lower-accuracy biometrics like facial recognition is used).

> "There is a possibility that (law enforcement officers) are collecting this data [in ways] that increase ethnic and racial disparities." -
> Jennifer Lynch, Senior Attorney at the Electronic Frontier Foundation

Jennifer Lynch, senior attorney at the Electronic Frontier Foundation, states that: "With biometric collection, specifically with mobile fingerprint readers, law-enforcement officers are able to collect information on the street, and there is a possibility that law officers are collecting this data [in ways] that increase the ethnic and racial disparities in cities. Any time that law enforcement officers are able to stop people on the street, it has been shown that they stop people from certain ethnic and minority groups much more frequently than [what they represent as a] percentage of the population as a whole." This approach creates the biometric equivalent of the infamous "stop and frisk" programme once employed in New York City.[35]

To guard against discriminatory screening and targeting, only the data of people convicted of a crime should be kept. It is difficult to disentangle whether minorities who live in high-crime areas are disproportionately targeted because of who they are, where they live, an inherent bias of the arresting officer, or a combination of these and many other factors. Therefore, until guilt has been proven, an innocent person is to be assumed innocent.

3. Manage mission creep

Fear of mission creep, also related to privacy concerns, refers to the use of biometric data for purposes other than that for which they were originally intended. The objective may not be malicious. Other government agencies may want to use biometric data to reduce costs, apprehend malfeasants, or accomplish socially beneficial goals. Additional uses are often advantageous and worthwhile. However, the new objective may be unrelated to the original purpose of the data. Indeed, the greater the effectiveness of biometrics, the more vulnerable it is to mission creep by other government departments.

One example is the Social Security number in the US. Originally meant for claiming unemployment benefits, it later applied to a wider range of processes like taxation and eventually became a form of identification, and therefore more valuable and open to theft and fraud. Roughly 6.1% of Americans, or 20m people, have more than one Social Security number, for example.[36]

Another example of mission creep is US IDENT. Originally developed in 1994 as a biometrics collection system for the Immigration and Naturalization Service (INS), it now conducts identification services on behalf of numerous government and external organisations, including Immigration and Customs Enforcement (ICE), the Department of Justice (DOJ), the FBI, and the Department of Defense (DOD).[37] The problem with enlarged use is that citizens may have authorised collection of their biometrics for one purpose but not another, and it is not clear what the protocols are for governments that wish to expand access to, and use of, the data.

There is no silver bullet to prevent mission creep – indeed, it may be desirable for biometric systems to expand over time to achieve efficiency gains. To ensure the public does not feel spied on, or otherwise cut out of the biometric process, governments need to take several steps. First, the goal and method of any biometric system should be clear and accessible to the public so they know why their data is being gathered, and they consent to it. As things change, it is likely that a programme's mission and method will change too. When those changes occur, they should be made public in order to foster debate. If the collected data is going to be used for another purpose, consent should be given by the person who owns the data, otherwise it becomes easy for mission creep to take hold and spread.

The goal and method of any biometric system should be clear and accessible to the public so they know why their data is being gathered, and they consent to it.

4. Beware of the honeypot effect

According to Daniel Bachenheimer, technical director at Accenture, "it is very difficult to do a search in a large biometric database with only two fingerprints' data. That's why agencies searching large [databases] use ten fingers, as well as additional information. For example, India's Aadhaar program, with almost a billion enrollees, requires all ten fingerprints and two irises to do a biometric search."

However, as the amount of data collected increases in size and complexity, databases become harder to search as they fragment into different platforms and systems that are often not interoperable. In response, it makes sense to centralise data in a single system that can be easily searched, rather than multiple smaller systems that have to be searched separately. This creates a "honeypot" where ever-greater quantities of data are stored in increasingly centralised systems, which becomes very valuable to a hacker or fraudster.

Furthermore, biometric data are permanent, so if data are exposed they can be impossible to retrieve. As Jennifer Lynch states, "People cannot change their fingerprints, the geometrics of their face, their DNA or their irises. If that data gets stolen, it's very different than a credit card or a PIN, which you can replace." If a biometric identity is a person's sole ID form, as it is for many enrolled in India's Aadhaar or Malaysia's MyKad programmes, mistaken identity can be difficult to rectify.

Security breaches are already a rising threat in today's digital age. A 2015 survey by Experian noted that adoption of cyber insurance policies by companies and institutions had more than doubled over the last year, from 10% in 2013 to 26% in 2014, with US companies reporting $40bn in losses from unauthorised computer use by employees in the last year.[38]

"Centralisation of sensitive, valuable information can create a 'honeypot' for malfeasants and hackers"
- Edgar Whitley, London School of Economics.

The US Government Accountability Office reports that "incidents involving breaches of sensitive data and information security incidents reports by federal agencies have risen from 5,503 in 2006 to 67,168 in 2014."[39] Of these, roughly half since 2009 have been of personally identifiable information (PII), such as name and Social Security number, but also of biometric information, with the number of incidents rising from 10,481 in 2009 to 27,624 in 2014.[40] A notable example is the security breach at the Office of Personnel Management in June 2015, where the fingerprints of approximately 5.6m security-cleared employees were stolen.

To mitigate the honeypot effect, governments need to realise that increased efficiency – through consolidation of biometric-linked data into a single database – is not always the best approach. Spreading information across multiple databases might be less efficient in terms of searching quickly through files, but it de-risks the honeypot effect. Just as some people keep different passwords for different websites, there needs to be an acceptance that some "friction" or inefficiency is worth it for the greater security it brings.

5. Get public buy-in

Biometric technology needs to be trusted by the public. This requires a careful balancing of the efficiency gains it offers against the corresponding infringements on privacy, and any data-security risks arising from the honeypot effect.

According to the UK Biometrics Commissioner, Alastair MacGregor, "it is crucial to engage with the public because some people are justifiably apprehensive. If governments are not upfront, there will be limited public buy-in. If there is a lack of public trust, the value of what could be a very effective tool, may be substantially undermined." When biometrics was introduced in some schools, for instance, parents were not always consulted, thereby undermining trust in the technology, according to Isabelle Moeller, CEO of the Biometrics Institute.

"If there is a lack of public trust, the value of what could be a very effective tool may be substantially undermined."
-Alastair MacGregor, UK Biometrics Commissioner

In the UK, the Labour government passed the Identity Cards Act in 2006, which legislated for the creation of biometric-based national ID cards linked to a biometric database called the National Identity Register. Public support at the time was relatively high, at 50%, but this fell dramatically after two discs containing the personal details of more than 25m Britons who were associated with the Child Benefit programme were lost.[41] Public support never recovered, and in 2010 after the Conservative-Liberal Democrat coalition was formed, the first bill put to Parliament was the abolition of the National ID card and database.[42]

Accountability, transparency and clear explanations regarding use can all foster public trust. Public buy-in can also be gained if governments take swift action in the event of any failures, whether technological or security-related, to ensure the public is confident in the government's control of the new technologies.

Estonia does particularly well in terms of fostering public trust in biometric technology. Estonian ID cards, embedded with fingerprint and iris images, can be used for voting, banking, paying taxes and receiving government transfers, along with 600 other e-services, but hold only a minimum amount of encrypted data so they can be replaced if lost. The cards increase efficiency: taxes can be filed within an hour and refunds are usually received within 48 hours.[43] Data collection and retention is transparent: people have the right to know what data are held on them and can cancel their consent to its use at any time. And finally, the system appears secure (there have been no security breaches since its inception). The databases that store Estonians' biographic and biometric data are fragmented across the country and backed up in embassies in allied countries.[44]

6. Plan for the long term

Governments must think ahead to potential unintended consequences to biometric rollout. It is not just a question of technologies being attractive: the overall system needs to be constructed in a sustainable and accessible way. For instance, is there a plan to ensure the financial sustainability of new technology systems which need continuous monitoring and maintenance? Investment needs to be earmarked to ensure that faulty technologies can quickly be replaced, as well as to finance data-management processes.

The other "long-term" factor is accessibility. Is a government confident that a biometric system will be truly universal? India's Aadhaar is a case in point. Fingerprints are more difficult to obtain from manual labourers than from office workers. Similarly, henna, a type of plant dye applied to the fingers and hands by Indian women during festivals, can decrease the quality of fingerprint images captured.[45] As Aadhaar is used to administer an increasing number of citizen–government interactions, such groups could become marginalised. 1.7% of India's population, or over 16m people, have been identified as "having intrinsically poor quality fingerprints" and so must participate with their irises only, which means lower accuracy.[46]

As explored above, universal biometrics can help to avoid racial bias in law-enforcement databases. But it can work only if access to digital services is universal too. It is not just about data, but also people's ability to use the tools for which the data is intended. People who need government services are often those most likely to find accessing such services difficult. In the UK, for instance, while the government is moving many public services online, there are people who do not feel confident using a computer, asking other people to go online for them, or who have no access to the Internet.[47]

Semi-skilled or unskilled manual labourers, pensioners, casual workers and the unemployed are more likely be offline, as are the elderly (32% of those aged 65 and above in 2015 had never used the Internet) and the disabled (37% were offline in 2012).

This means that the very people the government needs to assist – with unemployment benefits or pensioner support, for example – are the least likely to be online. In all digital rollouts of government services, if the process is not universal it risks being unequal and even entrenching existing socio-economic divides. Governments must therefore align biometric rollouts with broader information communications technology (ICT) penetration rates – and they must also ensure they monitor the impact of biometric technologies on key social service performance indicators, and that they publish that impact so that the public understands the benefits of new technologies.

Conclusion

Two extreme scenarios are presented in the debate about biometrics. Supporters argue that biometrics can solve many of the world's problems, saving time and money and increasing the security of transactions, all the while fostering economic development and financial inclusion. Opponents highlight risks to privacy, arguing that governments will use it to spy on and police their citizens in nefarious ways, and claim that saving ten minutes in the airport queue should not require people to involuntarily divulge personal, permanent information to a government whose holding and usage objectives may be opaque.

The truth lies somewhere between these extremes. The benefits of biometrics are real, and it can make the world a better place. In particular, it can help governments to better target public service provision to those most in need. Distributing fuel and food subsidies for the poor more effectively; helping those without collateral to open bank accounts by giving them a unique ID; and improving public services like hospitals, on which low-income individuals rely, are all examples of the poverty-fighting benefits of biometrics. Citizens can benefit from the use of biometrics to monitor attendance of their civil servants, to ensure those workers are carrying out the vital public services tasks on which populations, and especially the poor, depend.

But biometrics needs to be used responsibly, because the risks are also real. If biometric data are compromised, or law-enforcement agencies use them to discriminate against people, recovering from this will be difficult not just for the individual concerned, but for public opinion. The best strategy is an informed and open debate on governmental use of the technology, where facts and evidence drive decisions, and where technology has a clear goal in mind: to better serve citizens.

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