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,the free encyclopedia that anyone can edit.109,638 active editors 7,015,542 articles in EnglishMagic tablet from PergamonThe Orphic Hymns are a collection of 87 hymns in ancient Greek, addressed to various deities. Attributed in antiquity to the mythical poet Orpheus, they were composed in Asia Minor (in modern-day Turkey), most likely around the 2nd or 3rd centuries AD, and seem to have belonged to a cult community which used them in ritual. The collection is preceded by a proem (or prologue) in which Orpheus addresses the legendary poet Musaeus. The hymns in the collection, all of which are brief, typically call for the attention of the deity they address, describing them and their divinity, and appealing to them with a request. The first codex containing the Orphic Hymns to reach Western Europe arrived in Italy in the first half of the 15th century, and in 1500 the first printed edition of the Hymns was published in Florence. During the Renaissance, some scholars believed that the hymns were a genuine work of Orpheus; later, a more sceptical wave of scholarship argued for a dating in late antiquity. (Fullarticle...)Recently featured: HMSNeptune (1909)Nominative determinismDonkey Kong LandArchiveBy emailMore featured articlesAboutAquilegia oxysepala flower... that Aquilegia oxysepala (pictured), one of approximately 130 species of columbine, has been used medicinally for thousands of years?... that Jeff Baena accidentally earned a minor in medieval studies at film school?... that the European Athletics Championships first held a women's 400 metres race in 1958, twenty-four years after the first men's race?... that the Lutterodts were pioneers of African photography?... that the filmmakers of Cyborgs wrote dialogue in both Russian and Ukrainian to show the diversity of the eponymous soldiers who defended Donetsk Airport in late 2014?... that the killer of Anne Castle and William Bryan was convicted nearly 30 years after the murders?... that television producer Paul Graham insisted on "a big game feel" for the sportscast he considered his "baby"?... that the author of Tackle! found its sex scenes difficult to write because of her age?... that Stavatti Aerospace's only known facilities in 2021 were a "one-person office suite", a "machine shop ... slightly larger than a basketball court", and the CEO's house?ArchiveStart a new articleNominate an articleTrifid and Lagoon nebulaeThe Vera C. Rubin Observatory in Chile releases the first light images (example shown) from its new 8.4-metre (28ft) telescope.In basketball, the Oklahoma City Thunder defeat the Indiana Pacers to win the NBA Finals.An attack on a Greek Orthodox church in Damascus, Syria, kills at least 25 people.The United States conducts military strikes on three nuclear facilities in Iran.In rugby union, the Crusaders defeat the Chiefs to win the Super Rugby Pacific final.Ongoing: Gaza warIranIsrael warRussian invasion of UkrainetimelineSudanese civil wartimelineRecent deaths: Takahiro ShiraishiShefali JariwalaClark OlofssonGrard LefrancTakutai Tarsh KempArnaldo PomodoroNominate an articleJune 29: Feast of Saints Peter and Paul (Western Christianity)Jayne Mansfield1613 The original Globe Theatre in London burned to the ground after a cannon employed for special effects misfired during a performance of Henry VIII and ignited the roof.1764 One of the strongest tornadoes in history struck Woldegk in present-day northeastern Germany, killing one person.1950 The United States defeated England during the FIFA World Cup in one of the greatest upsets in the competition's history.1967 Actress Jayne Mansfield (pictured), her boyfriend Sam Brody, and their driver were killed in a car accident outside of New Orleans, while her children Mikls, Zoltn, and Mariska Hargitay escaped with only minor injuries.2020 Reddit banned r/The_Donald, a pro-Trump subreddit, for rule violations and antagonizing the company.Ernest Fanelli (b.1860)Ludwig Beck (b.1880)Paul Klee (d.1940)Nestor Binabo (d.2023)More anniversaries: June 28June 29June 30ArchiveBy emailList of days of the yearAboutThe thousand-yard stare (also referred to as the two-thousand-yard stare) is the blank, unfocused gaze of people experiencing dissociation due to acute stress or traumatic events. The phrase was originally used to describe war combatants and the post-traumatic stress they exhibited but is now also used to refer to an unfocused gaze observed in people under any stressful situation, or in people with certain mental health conditions. The thousand-yard stare is sometimes described as an effect of shell shock or combat stress reaction, along with other mental health conditions. However, it is not a formal medical term. This painting by the war artist Thomas C. Lea III, titled Marines Call It That 2,000 Yard Stare, popularized the term after it was published in Life in 1945. It depicts an unnamed US Marine at the Battle of Peleliu, which took place in 1944.Painting credit: Thomas C. Lea IIIRecently featured: Myosotis scorpioidesWhitehead's trogonAtacamiteArchiveMore featured picturesCommunity portal The central hub for editors, with resources, links, tasks, and announcements.Village pump Forum for discussions about Wikipedia itself, including policies and technical issues.Site news Sources of news about Wikipedia and the broader Wikimedia movement.Teahouse Ask basic questions about using or editing Wikipedia.Help desk Ask questions about using or editing Wikipedia.Reference desk Ask research questions about encyclopedic topics.Content portals A unique way to navigate the encyclopedia.Wikipedia is written by volunteer editors and hosted by the Wikimedia Foundation, a non-profit organization that also hosts a range of other volunteer projects: CommonsFree media repository MediaWikiWiki software development Meta-WikiWikimedia project coordination WikibooksFree textbooks and manuals WikidataFree knowledge base WikinewsFree-content news WikiquoteCollection of quotations WikisourceFree-content library WikispeciesDirectory of species WikiversityFree learning tools WikivoyageFree travel guide WiktionaryDictionary and thesaurusThis Wikipedia is written in English. Many other Wikipedias are available; some of the largest are listed below. 1,000,000+ articles DeutschEspaolFranaisItalianoNederlandsPolskiPortugusSvenskaTing Vit 250,000+ articles Bahasa IndonesiaBahasa MelayuBn-lm-gCataletinaDanskEestiEsperantoEuskaraMagyarNorsk bokmlRomnSimple EnglishSloveninaSrpskiSrpskohrvatskiSuomiTrkeOzbekcha 50,000+ articles AsturianuAzrbaycancaBosanskiFryskGaeilgeGalegoHrvatskiKurdLatvieuLietuviNorsk nynorskShqipSlovenina Retrieved from " 2Calendar yearYearsMillennium2ndmillenniumCenturies16thcentury17thcentury 18thcenturyDecades1590s1600s1610s 1620s1630sYears1610161116121613 161416151616vteAugust 29: The Battle of Cape Corvo is fought between Sicily and the Ottoman Empire1613 by topicArts and scienceArchitectureArtLiteratureMusicScienceLeadersState leadersColonial governorsReligious leadersBirth and death categoriesBirths DeathsEstablishments and disestablishments categoriesEstablishments DisestablishmentsWorks categoryWorksvte1613 in various calendarsGregorian calendar1613MDCXIIIAb urbe condita2366Armenian calendar1062 Assyrian calendar6363Balinese saka calendar15341535Bengali calendar10191020Berber calendar2563English Regnal year10Ja.111Ja.1Buddhist calendar2157Burmese calendar975Byzantine calendar71217122Chinese calendar (WaterRat)4310 or 4103to (WaterOx)4311 or 4104Coptic calendar13291330Discordian calendar2779Ethiopian calendar16051606Hebrew calendar53735374Hindu calendars- Vikram Samvat16691670- Shaka Samvat15341535- Kali Yuga47134714Holocene calendar11613Igbo calendar613614Iranian calendar991992Islamic calendar10211022Japanese calendarKeich 18()Javanese calendar15331534Julian calendarGregorian minus 10 daysKorean calendar3946Minguo calendar299 before ROC299Nanakshahi calendar145Thai solar calendar21552156Tibetan calendar(male Water-Rat)1739 or 1358 or 586to(female Water-Ox)1740 or 1359 or 5871613 (MDCXIII) was a common year starting on Tuesday of the Gregorian calendarand a common year starting on Friday of the Julian calendar, the 1613th year of the Common Era (CE) and Anno Domini (AD) designations, the 613th year of the 2ndmillennium, the 13th year of the 17thcentury, and the 4th year of the 1610s decade. As of the start of 1613, the Gregorian calendar was 10 days ahead of the Julian calendar, which remained in localized use until 1923. Calendar year January 11 Workers in a sandpit in the Dauphin region of France discover the skeleton of what is alleged to be a 30-foot tall man (the remains, it is supposed, of the giant Teutobochus, a legendary Gallic king who fought the Romans).[1]January 20 King James I of England successfully mediates the Treaty of Knred between Denmark and Sweden.[2]February 14 Elizabeth, daughter of King James I of England, marries Frederick V, Elector Palatine.[3]February 24 King Anaukpetlun of Burma blockades the Portuguese port at Syriam with 80 warships and 3,000 men, then sets about to tunnel into the city.March 3 (February 21 O.S.) An assembly of the Russian Empire elects Mikhail Romanov Tsar of Russia, ending the Time of Troubles. The House of Romanov will remain a ruling dynasty until 1917.March 27 The first English child is born in Canada at Cuper's Cove, Newfoundland to Nicholas Guy.March 29Explorer Samuel de Champlain becomes the first unofficial Governor of New France in Canada.Burmese soldiers, tunneling under the walls of the Portuguese colonial fortress at Syriam (now Thanlyin), bring down a section of the walls and sack the city. Portuguese Governor Filipe de Brito e Nicote and rebel Burmese General Natshinnaung are captured, and executed by impalement on April 9.April 13 Samuel Argall captures Algonquian princess Pocahontas in Passapatanzy, Virginia, to ransom her for some English prisoners held by her father, Chief Powhatan. She is brought to Henricus as a hostage.[4]May 12 Mikhail Romanov arrives in Moscow to begin his reign as Tsar of Russia, after having been elected on March 3.May 14The city of Hanthawaddy (now Bago) is restored as the capital of Burma by King Anaukpetlun, who relocates the government from Ava (now Inwa).The ruler of the principality of Martaban, Binnya Dala, surrenders to the armies of King Anaukpetlun of Burma.May 23 War of the Montferrat Succession: The defenders of the Italian city of Nizza Monferrato successfully resist a nine-day siege by the troops of Charles Emmanuel I, Duke of Savoy.May 27 After getting an official proclamation that he is the French Governor of New France, explorer Samuel de Champlain begins exploration of the area westward from Quebec, traveling along the Ottawa River.June 28 (July 8 N.S.) From Jamestown, John Rolfe makes the first shipment to England of tobacco grown in Virginia, dispatching it on the ship The Elizabeth. [5] The tobacco arrives in England after a voyage of three weeks.June 29 Fire destroys London's famed Globe Theatre, during a performance of Shakespeare's Henry VIII.[6]July 20 (July 30 N.S.) The first American-grown tobacco, produced in the British colony of Virginia, arrives in England after being dispatched 22 days earlier by John Rolfe. [5]July 26 Diego Marn de Negron, the Spanish Governor of Rio de la Plata y Paraguay, is assassinated by poisoning at his palace in Buenos Aires.C. Antonio Zinny, History of the governors of the Argentine provinces from 1810 to the present (Editoriales Huemul, 1941) p.105July 28 Gregor Richter, the chief pastor of Grlitz, denounces Jacob Boehme as a heretic, in his Sunday sermon.August 29 The Sicilians under de Aragon defeat the trade fleet of the Ottoman Empire, ending the Battle of Cape Corvo.September 29 The New River is opened, to supply London with drinking water from Hertfordshire.October 21 Gabriel Bathory, ruler of the Principality of Transylvania, is removed from office by vote of the nobles meeting at Gyulafehrvr (now Alba Iulia in Romania).[7]:279 Bathory refuses to vacate the palace at the Transylvanian capital at Vrad, (now Oradea in Romania), and is murdered on October 27.[7]October 23 Gabriel Bethlen is elected as the new Prince of Transylvania.[8]October 28 Keich embassy: Hasekura Tsunenaga departs Japan in the Date Maru with a Japanese diplomatic mission to the Holy See, scheduled to first travel to Acapulco in New Spain, with a goal of concluding an agreement between Tokugawa Ieyasu and the East India Company, permitting English merchants to live and trade in Japan.November 3 English royal favourite Robert Carr is created 1st Earl of Somerset.November 30 King Anaukpetlun of Burma sends an army of 4,000 troops to drive the Siamese occupiers from the Tenasserim coast.December 26 The Date Maru, carrying the Japanese diplomatic mission commanded Hasekura Tsunenaga, reaches North America, sighting Cape Mendocino on the California coast.[9]The Earl of Somerset marries Frances Howard, following the September 25 annulment of her marriage to Robert Devereux, 3rd Earl of Essex; the event is the inspiration for John Donne's Eclogue.[10]December 26 The Burmese Army defeats the Siamese Army at Tavoy. The city is now part of Myanmar as Dawei.December 27 Mateo Leal de Ayala becomes the new Governor of Rio de la Plata y Paraguay, covering what will become the nations of Argentina, Chile and Paraguay. He succeeds Diego Marn de Negron, who was poisoned on July 26.A locust swarm destroys La Camarque, France.Kuwait City is founded.Sultan Agung of Mataram takes the throne of the kingdom of Mataram in Java.Near Jamestown, Virginia, Sir Thomas Dale starts a settlement called Bermuda City, which later becomes part of Hopewell, Virginia.Mattia PretiStjepan GradiAndr Le NtreEmpress Dowager XiaozhuangClaude PerraultJanuary 14 Pier Martire Armani, Italian painter (d. 1699)January 15 Giovanni Pietro Bellori, Italian art historian (d. 1696)January 21 George Gillespie, Scottish theologian (d. 1648)February 2Nol Chabanel, French Jesuit missionary at Sainte-Marie among the Hurons (d. 1649)William Thomas, Welsh Anglican bishop (d. 1689)February 7 Johannes Musaeus, German theologian (d. 1681)February 24 Mattia Preti, Italian painter (d. 1699)February 28 John Pearson, English theologian and scholar (d. 1686)March 6Stjepan Gradi, Croatian philosopher and scientist (d. 1683)Anna Moroni, Italian educator (d. 1675)March 11 Francesco Caetani, 8th Duke of Sermoneta, Governor of the Duchy of Milan (d. 1683)March 12 Andr Le Ntre, French landscape and garden designer (d. 1700)[11]March 19 John Swinfen, English politician (d. 1694)March 24 Antonia of Wrttemberg, princess, literary figure, patron and Christian Kabbalist (d. 1679)March 28 Empress Dowager Xiaozhuang, concubine of Qing dynasty ruler Hong Taiji (d. 1688)[12]March 29 Louis-Isaac Lemaistre de Sacy, French Bible translator (d. 1684)April 1Giulio Bartolocci, Italian Biblical scholar (d. 1687)Charles de Saint-vremond, French soldier and writer (d. 1703)April 7 Gerrit Dou, Dutch painter (d. 1675)April 18 Philip Wharton, 4th Baron Wharton, English soldier (d. 1696)April 21 Franciscus Plante, Dutch painter, chaplain (d. 1690)April 29 Christoph Bach, German musician (d. 1661)May 9 Mattias de' Medici, Italian noble (d. 1667)May 10 Franois Chauveau, French painter (d. 1676)May 15 George Seton, Lord Seton, Scottish noble (d. 1648)May 31 John George II, Elector of Saxony (16561680) (d. 1680)June 1 William Wirich, Count of Daun-Falkenstein, German nobleman (d. 1682)June 13 Johann Ernst, Count of Hanau-Mnzenberg (16411642) (d. 1642)June 16 John Cleveland, English poet (d. 1658)July 15 Gu Yanwu, Chinese philologist and geographer (d. 1682)July 16 Alderano Cybo, Catholic cardinal (d. 1700)August 7 William Frederick, Prince of Nassau-Dietz, Dutch stadtholder (d. 1664)August 15 Gilles Mnage, French scholar (d. 1692)August 18 Sir Thomas Peyton, 2nd Baronet, English politician (d. 1684)August 20 Duchess Elisabeth Sophie of Mecklenburg, German poet composer and (by marriage) Duchess of Brunswick-Lneburg (d. 1676)August 24 Bartholomew Holzhauser, German priest, founder of a religious community, visionary, writer of prophecies (d. 1658)August 29 John Jolliffe, English politician and businessman (d. 1680)September 8 Henri Albert de La Grange d'Arquien, Catholic cardinal (d. 1707)September 15 Franois de La Rochefoucauld, French writer (d. 1680)[13]September 19 Sir John Norwich, 1st Baronet, English Member of Parliament (d. 1661)September 25 Claude Perrault, French architect (d. 1688)October 3 Marion Delorme, French courtesan known for her relationships with the important men of her time (d. 1650)October 12 Jacques d'Arthois, Flemish painter (d. 1686)October 13Luisa de Guzmn, Duchess of Braganza, queen consort of Portugal (d. 1666)Adriaan Heereboord, Dutch philosopher (d. 1661)October 19 Charles of Sezze, Italian Franciscan friar and saint (d. 1670)October 28 Edmund Bowyer, English politician (d. 1681)November 5 Isaac de Benserade, French poet (d. 1691)[14]November 12 Sir Ralph Verney, 1st Baronet, of Middle Claydon, English Baronet (d. 1696)November 16 Frederick, Prince of Anhalt-Harzgerode (16351670) (d. 1670)November 20 Tyman Oosdorp, Dutch Golden Age brewer and magistrate of Haarlem (d. 1668)November 24 John Knight, Member of the Parliament of England (d. 1683)November 25 Philip VII, Count of Waldeck-Wildungen (16381645) (d. 1645)December 4 (bapt.) Samuel Butler, English satirist (d. 1680)December 10 Izaak van Oosten, Flemish painter (d. 1661)December 11 Amar Singh Rathore, Rajput nobleman affiliated with the royal house of Marwar (d. 1644)December 23 Carl Gustaf Wrangel, Field Marshal of Sweden (d. 1676)December 28 Bullen Reymes, English courtier, diplomat and politician (d. 1672)Henry Vane, English politician (d. 1662)Khushal Khan Khattak, Afghan poet (d. 1690)Richard Crashaw, English poet (d. 1649)Juan Garca Lpez-RicoIkeda TerumasaSigismund BthoryJanuary 2 Salima Sultan Begum, Empress of the Mughal Empire (b. 1539)January 12 George Blackwell, English Catholic archpriest (b. 1545)January 18 Antoon Claeissens, Flemish Baroque painter (b. 1536)January 27 Anna of Saxony, German noblewoman (b. 1567)January 28 Thomas Bodley, English diplomat and library founder (b. 1545)[15]February 14 Juan Garca Lpez-Rico, Spanish Catholic priest from the Trinitarian Order, founded the Order of Discalced Carmelites (b. 1561)February 16 Johannes Letzner, German Protestant priest and historian (b. 1531)February 27 Pietro Facchetti, Italian painter (b. 1539)March 2 Rudolph Snellius, Dutch linguist and mathematician (b. 1546)March 13 Giovanni Battista Caccini, Italian artist (b. 1556)March 16Sigrid Sture, Swedish Governor (b. 1538)Ikeda Terumasa, Japanese daimy (b. 1565)March 23 Jernimo de Ayanz y Beaumont, Spanish inventor (b. 1553)March 27 Sigismund Bthory, Prince of Transylvania (b. 1572)April 27 Robert Abercromby, Scottish Jesuit missionary (b. 1532)June 3 Allahverdi Khan, Georgian-born Iranian general (b. 1590)June 8 Cigoli, Italian painter (b. 1559)June 15 Magdalena Moons, Dutch heroine (b. 1541)July 2 Bartholomaeus Pitiscus, German astronomer and mathematician (b. 1561)July 19 Nicolaus van Aelst, Flemish engraver (b. 1526)July 20 Sebastian Lubomirski, Polish-Lithuanian nobleman (szlachcic) (b. c. 1546)July 30 Henry Julius, Duke of Brunswick-Lneburg (b. 1564)August 1Francesco Grimaldi, Italian architect (b. 1543)Thomas Twyne, English actor (b. 1543)August 7 Thomas Fleming, English judge (b. 1544)August 14 David Lindsay, Scottish bishop (b. 1531)August 18 Giovanni Artusi, Italian composer (b. c. 1540)August 22 Dominicus Baudius, Dutch historian and poet (b. 1561)August 25 William Waldegrave, English Member of Parliament (b. 1540)September 8Carlo Gesualdo, Italian composer (b. 1566)[16]James Pemberton, British goldsmith (b. 1550)September 14 Thomas Overbury, English poet and essayist (murdered) (b. 1581)October 9 Henry Constable, English poet (b. 1562)October 11 John Petre, 1st Baron Petre, English politician (b. 1549)October 22 Mathurin Rgnier, French satirist (b. 1573)October 26 Johann Bauhin, Swiss botanist (b. 1541)October 27 Gabriel Bthory, Prince of Transylvania (b. 1589)November 4 Cristbal Rodrguez Jurez, Spanish Catholic archbishop (b. 1547)November 16 Trajano Boccalini, Italian satirist (b. 1556)November 21 Rose Lok, English Marian exile (b. 1526)November 23 Charles Philippe de Cro, Marquis dHavr, Belgian noble and politician (b. 1549)November 26 Henry Berkeley, 7th Baron Berkeley, English politician (b. 1534)December 6 Anton Praetorius, German pastor (b. 1560)December 7 Simon VI, Count of Lippe, imperial count and ruler of the County of Lippe (Germany) since 1563 (b. 1554)date unknownPhng Khc Khoan, Vietnamese military strategist, politician, diplomat and poet (b. 1528)Beatrice Michiel, Venetian spy (b. 1553)^ W.A. 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ISBN978-0-404-60195-9. {{cite book}}: ISBN / Date incompatibility (help)^ Church Monuments: Journal of the Church Monuments Society. The Society. 1993. p.61.^ David Mason Greene; Constance Green (1985). Greene's Biographical Encyclopedia of Composers. Reproducing Piano Roll Fnd. p.81. ISBN978-0-385-14278-6.Retrieved from " 3One hundred years, from 1501 to 1600This article needs additional citations for verification. Please help improve this article by adding citations to reliable sources. Unsourced material may be challenged and removed.Find sources:"16th century"news newspapers books scholar JSTOR (September 2022) (Learn how and when to remove this message)Millennia2ndmillenniumCenturies15thcentury16thcentury17thcenturyTimelines15thcentury16thcentury17thcenturyState leaders15thcentury16thcentury17thcenturyDecades1500s1510s1520s1530s1540s1550s1560s1570s1580s1590sCategories:Births Deaths Establishments DisestablishmentsvteThe world map by the Italian Amerigo Vespucci (from whose name the word America is derived) and Belgian Gerardus Mercator shows (besides the classical continents Europe, Africa, and Asia) the Americas as America sive India Nova', New Guinea, and other islands of Southeast Asia, as well as a hypothetical Arctic continent and a yet undetermined Terra Australis.[1]The 16th century began with the Julian year 1501 (represented by the Roman numerals MDI) and ended with either the Julian or the Gregorian year 1600 (MDC), depending on the reckoning used (the Gregorian calendar introduced a lapse of 10 days in October 1582).[1]The Renaissance in Italy and Europe saw the emergence of important artists, authors and scientists, and led to the foundation of important subjects which include accounting and political science. Copernicus proposed the heliocentric universe, which was met with strong resistance, and Tycho Brahe refuted the theory of celestial spheres through observational measurement of the 1572 appearance of a Milky Way supernova. These events directly challenged the long-held notion of an immutable universe supported by Ptolemy and Aristotle, and led to major revolutions in astronomy and science. Galileo Galilei became a champion of the new sciences, invented the first thermometer and made substantial contributions in the fields of physics and astronomy, becoming a major figure in the Scientific Revolution in Europe.Spain and Portugal colonized large parts of Central and South America, followed by France and England in Northern America and the Lesser Antilles. The Portuguese became the masters of trade between Brazil, the coasts of Africa, and their possessions in the Indies, whereas the Spanish came to dominate the Greater Antilles, Mexico, Peru, and opened trade across the Pacific Ocean, linking the Americas with the Indies. English and French privateers began to practice persistent theft of Spanish and Portuguese treasures. This era of colonialism established mercantilism as the leading school of economic thought, where the economic system was viewed as a zero-sum game in which any gain by one party required a loss by another. The mercantilist doctrine encouraged the many intra-European wars of the period and arguably fueled European expansion and imperialism throughout the world until the 19th century or early 20th century.The Reformation in central and northern Europe gave a major blow to the authority of the papacy and the Catholic Church. In England, the British-Italian Alberico Gentili wrote the first book on public international law and divided secularism from canon law and Catholic theology. European politics became dominated by religious conflicts, with the groundwork for the epochal Thirty Years' War being laid towards the end of the century.In the Middle East, the Ottoman Empire continued to expand, with the sultan taking the title of caliph, while dealing with a resurgent Persia. Iran and Iraq were caught by a major popularity of the Shia sect of Islam under the rule of the Safavid dynasty of warrior-mystics, providing grounds for a Persia independent of the majority-Sunni Muslim world.[2]In the Indian subcontinent, following the defeat of the Delhi Sultanate and Vijayanagara Empire, new powers emerged, the Sur Empire founded by Sher Shah Suri, Deccan sultanates, Rajput states, and the Mughal Empire[3] by Emperor Babur, a direct descendant of Timur and Genghis Khan.[4] His successors Humayun and Akbar, enlarged the empire to include most of South Asia.Japan suffered a severe civil war at this time, known as the Sengoku period, and emerged from it as a unified nation under Toyotomi Hideyoshi. China was ruled by the Ming dynasty, which was becoming increasingly isolationist, coming into conflict with Japan over the control of Korea as well as Japanese pirates.In Africa, Christianity had begun to spread in Central Africa and Southern Africa. Until the Scramble for Africa in the late 19th century, most of Africa was left uncolonized.For timelines of earlier events, see 15th century and Timeline of the Middle Ages.Main article: 1500sMona Lisa, by Leonardo da Vinci, c.15031506, one of the world's best-known paintings1501: Michelangelo returns to his native Florence to begin work on the statue David.1501: Safavid dynasty reunifies Iran and rules over it until 1736. Safavids adopt a Shia branch of Islam.[5]1501: First Battle of Cannanore between the Third Portuguese Armada and Kingdom of Cochin under Joo da Nova and Zamorin of Kozhikode's navy marks the beginning of Portuguese conflicts in the Indian Ocean.1502: First reported African slaves in the New World1502: The Crimean Khanate sacks Sarai in the Golden Horde, ending its existence.1503: Spain defeats France at the Battle of Cerignola. Considered to be the first battle in history won by gunpowder small arms.1503: Leonardo da Vinci begins painting the Mona Lisa and completes it three years later.1503: Nostradamus is born on either December 14 or December 21.1504: A period of drought, with famine in all of Spain.1504: Death of Isabella I of Castile; Joanna of Castile becomes the Queen.1504: Foundation of the Sultanate of Sennar by Amara Dunqas, in what is modern Sudan1505: Zhengde Emperor ascends the throne of Ming dynasty.1505: Martin Luther enters St. Augustine's Monastery at Erfurt, Germany, on 17 July and begins his journey to instigating the Reformation.1505: Sultan Trenggono builds the first Muslim kingdom in Java, called Demak, in Indonesia. Many other small kingdoms were established in other islands to fight against Portuguese. Each kingdom introduced local language as a way of communication and unity.1506: Leonardo da Vinci completes the Mona Lisa.1506: King Afonso I of Kongo wins the battle of Mbanza Kongo, resulting in Catholicism becoming Kongo's state religion.Battle of Cerignola: El Gran Capitan finds the corpse of Louis d'Armagnac, Duke of Nemours1506: At least two thousand converted Jews are massacred in a Lisbon riot, Portugal.1506: Christopher Columbus dies in Valladolid, Spain.1506: Poland is invaded by Tatars from the Crimean Khanate.1507: The first recorded epidemic of smallpox in the New World on the island of Hispaniola. It devastates the native Tano population.[6]1507: Afonso de Albuquerque conquered Hormuz and Muscat, among other bases in the Persian Gulf, taking control of the region at the entrance of the Gulf.1508: The Christian-Islamic power struggle in Europe and West Asia spills over into the Indian Ocean as Battle of Chaul during the Portuguese-Mamluk War15081512: Michelangelo paints the Sistine Chapel ceiling.1509: The defeat of joint fleet of the Sultan of Gujarat, the Mamlk Burji Sultanate of Egypt, and the Zamorin of Calicut with support of the Republic of Venice and the Ottoman Empire in Battle of Diu marks the beginning of Portuguese dominance of the Spice trade and the Indian Ocean.1509: The Portuguese king sends Diogo Lopes de Sequeira to find Malacca, the eastern terminus of Asian trade. After initially receiving Sequeira, Sultan Mahmud Shah captures and/or kills several of his men and attempts an assault on the four Portuguese ships, which escape.[7] The Javanese fleet is also destroyed in Malacca.1509: Krishnadevaraya ascends the throne of Vijayanagara Empire.Main article: 1510sAfonso de Albuquerque15091510: The 'great plague' in various parts of Tudor England.[8]1510: Afonso de Albuquerque of Portugal conquers Goa in India.1511: Afonso de Albuquerque of Portugal conquers Malacca, the capital of the Sultanate of Malacca in present-day Malaysia.1512: Copernicus writes Commentariolus, and proclaims the Sun the center of the Solar System.1512: The southern part (historical core) of the Kingdom of Navarre is invaded by Castile and Aragon.1512: Qutb Shahi dynasty, founded by Quli Qutb Mulk, rules Golconda Sultanate until 1687.1512: The first Portuguese exploratory expedition was sent eastward from Malacca (in present-day Malaysia) to search for the 'Spice Islands' (Maluku) led by Francisco Serro. Serro is shipwrecked but struggles on to Hitu (northern Ambon) and wins the favour of the local rulers.[9]1513: Machiavelli writes The Prince, a treatise about political philosophy1513: The Portuguese mariner Jorge lvares lands at Macau, China, during the Ming dynasty.1513: Henry VIII defeats the French at the Battle of the Spurs.1513: The Battle of Flodden Field in which invading Scots are defeated by Henry VIII's forces.1513: Sultan Selim I ("The Grim") orders the massacre of Shia Muslims in Anatolia (present-day Turkey).1513: Vasco Nez de Balboa, in service of Spain arrives at the Pacific Ocean (which he called Mar del Sur) across the Isthmus of Panama. He was the first European to do so.1514: The Battle of Orsha halts Muscovy's expansion into Eastern Europe.1514: Dzsa rebellion (peasant revolt) in Hungary.Martin Luther initiated the Reformation with his Ninety-five Theses in 1517.1514: The Battle of Chaldiran, the Ottoman Empire gains decisive victory against Safavid dynasty.1515: Ascension of Francis I of France as King of France following the death of Louis XII.1515: The Ottoman Empire wrests Eastern Anatolia from the Safavids after the Battle of Chaldiran.1515: The Ottomans conquer the last beyliks of Anatolia, the Dulkadirs and the Ramadanids.15161517: The Ottomans defeat the Mamluks and gain control of Egypt, Arabia, and the Levant.1517: The Sweating sickness epidemic in Tudor England.[10]1517: The Reformation begins when Martin Luther posts his Ninety-five Theses in Saxony.1518: The Treaty of London was a non-aggression pact between the major European nations. The signatories were Burgundy, France, England, the Holy Roman Empire, the Netherlands, the Papal States and Spain, all of whom agreed not to attack one another and to come to the aid of any that were under attack.1518: Mir Chakar Khan Rind leaves Baluchistan and settles in Punjab.1518: Leo Africanus, also known as al-Hasan ibn Muhammad al-Wazzan al-Fasi, an Andalusian Berber diplomat who is best known for his book Descrittione dellAfrica (Description of Africa), is captured by Spanish pirates; he is taken to Rome and presented to Pope Leo X.1518: The dancing plague of 1518 begins in Strasbourg, lasting for about one month.1519: Leonardo da Vinci dies of natural causes on May 2.Europe at the time of the accession of Charles V in 15191519: Wang Yangming, the Chinese philosopher and governor of Jiangxi province, describes his intent to use the firepower of the fo-lang-ji, a breech-loading Portuguese culverin, in order to suppress the rebellion of Prince Zhu Chenhao.1519: Barbary pirates led by Hayreddin Barbarossa, a Turk appointed to ruling position in Algiers by the Ottoman Empire, raid Provence and Toulon in southern France.1519: Death of Emperor Maximilian; Charles I of Austria, Spain, and the Low Countries becomes Emperor of Holy Roman Empire as Charles V, Holy Roman Emperor (ruled until 1556).15191522: Spanish expedition commanded by Magellan and Elcano are the first to Circumnavigate the Earth.15191521: Hernn Corts leads the Spanish conquest of the Aztec Empire.Main article: 1520sFerdinand Magellan led the first expedition that circumnavigated the globe in 15191522.15201566: The reign of Suleiman the Magnificent marks the zenith of the Ottoman Empire.1520: The first European diplomatic mission to Ethiopia, sent by the Portuguese, arrives at Massawa 9 April, and reaches the imperial encampment of Emperor Dawit II in Shewa 9 October.1520: Vijayanagara Empire forces under Krishnadevaraya defeat the Adil Shahi under at the Battle of Raichur1520: Sultan Ali Mughayat Shah of Aceh begins an expansionist campaign capturing Daya on the west Sumatran coast (in present-day Indonesia), and the pepper and gold producing lands on the east coast.1520: The Portuguese established a trading post in the village of Lamakera on the eastern side of Solor (in present-day Indonesia) as a transit harbour between Maluku and Malacca.1521: Belgrade (in present-day Serbia) is captured by the Ottoman Empire.1521: After building fortifications at Tuen Mun, the Portuguese attempt to invade Ming dynasty China, but are expelled by Chinese naval forces.1521: Philippines encountered by Ferdinand Magellan. He was later killed in the Battle of Mactan in central Philippines in the same year.1521: Jiajing Emperor ascended the throne of Ming dynasty, China.1521: November, Ferdinand Magellan's expedition reaches Maluku (in present-day Indonesia) and after trade with Ternate returns to Europe with a load of cloves.1521: Pati Unus leads the invasion of Malacca (in present-day Malaysia) against the Portuguese occupation. Pati Unus was killed in this battle, and was succeeded by his brother, sultan Trenggana.1522: Rhodes falls to the Ottomans of Suleiman the Magnificent.[11]Sack of Rome of 1527 by Charles V's forces (painting by Johannes Lingelbach)1522: The Portuguese ally themselves with the rulers of Ternate (in present-day Indonesia) and begin construction of a fort.[9]1522: August, Luso-Sundanese Treaty signed between Portugal and Sunda Kingdom granted Portuguese permit to build fortress in Sunda Kelapa.1523: Sweden gains independence from the Kalmar Union.1523: The Cacao bean is introduced to Spain by Hernn Corts15241525: German Peasants' War in the Holy Roman Empire.1524: Giovanni da Verrazzano is the first European to explore the Atlantic coast of North America between South Carolina and Newfoundland.1524: Ismail I, the founder of Safavid dynasty, dies and Tahmasp I becomes king.Gun-wielding Ottoman Janissaries and defending Knights of Saint John at the siege of Rhodes in 1522, from an Ottoman manuscript1525: Timurid Empire forces under Babur defeat the Lodi dynasty at the First Battle of Panipat, end of the Delhi Sultanate.1525: German and Spanish forces defeat France at the Battle of Pavia, Francis I of France is captured.1526: The Ottomans defeat the Kingdom of Hungary at the Battle of Mohcs.1526: Mughal Empire, founded by Babur.1527: Sack of Rome with Pope Clement VII escaping and the Swiss Guards defending the Vatican being killed. The sack of the city of Rome considered the end of the Italian Renaissance.1527: Protestant Reformation begins in Sweden.1527: The last ruler of Majapahit falls from power. This state (located in present-day Indonesia) was finally extinguished at the hands of the Demak. A large number of courtiers, artisans, priests, and members of the royalty moved east to the island of Bali; however, the power and the seat of government transferred to Demak under the leadership of Pangeran, later Sultan Fatah.1527: June 22, The Javanese Prince Fatahillah of the Cirebon Sultanate successfully defeated the Portuguese armed forces at the site of the Sunda Kelapa Harbor. The city was then renamed Jayakarta, meaning "a glorious victory." This eventful day came to be acknowledged as Jakarta's Founding Anniversary.1527: Mughal Empire forces defeat the Rajput led by Rana Sanga of Mewar at the Battle of Khanwa1529: The Austrians defeat the Ottoman Empire at the siege of Vienna.1529: Treaty of Zaragoza defined the antimeridian of Tordesillas attributing the Moluccas to Portugal and Philippines to Spain.1529: Imam Ahmad Gurey defeats the Ethiopian Emperor Dawit II in the Battle of Shimbra Kure, the opening clash of the EthiopianAdal War.Main article: 1530sSpanish conquistadors with their Tlaxcallan allies fighting against the Otomies of Metztitlan in present-day Mexico, a 16th-century codex15311532: The Church of England breaks away from the Catholic Church and recognizes King Henry VIII as the head of the Church.1531: The Inca Civil War is fought between the two brothers, Atahualpa and Huscar.1532: Francisco Pizarro leads the Spanish conquest of the Inca Empire.1532: Foundation of So Vicente, the first permanent Portuguese settlement in the Americas.1533: Anne Boleyn becomes Queen of England.1533: Elizabeth Tudor is born.1534: Jacques Cartier claims Canada for France.1534: The Ottomans capture Baghdad from the Safavids.1534: Affair of the Placards, where King Francis I becomes more active in repression of French Protestants.1535: The Mnster Rebellion, an attempt of radical, millennialist, Anabaptists to establish a theocracy, ends in bloodshed.1535: The Portuguese in Ternate depose Sultan Tabariji (or Tabarija) and send him to Portuguese Goa where he converts to Christianity and bequeaths his Portuguese godfather Jordao de Freitas the island of Ambon.[12] Hairun becomes the next sultan.1536: Catherine of Aragon dies in Kimbolton Castle, in England.Territorial expansion of the Ottoman Empire under Suleiman (in red and orange)1536: In England, Anne Boleyn is beheaded for adultery and treason.1536: Establishment of the Inquisition in Portugal.1536: Foundation of Buenos Aires (in present-day Argentina) by Pedro de Mendoza.1537: The Portuguese establish Recife in Pernambuco, north-east of Brazil.1537: William Tyndale's partial translation of the Bible into English is published, which would eventually be incorporated into the King James Bible.1538: Gonzalo Jimnez de Quesada founds Bogot.1538: SpanishVenetian fleet is defeated by the Ottoman Turks at the Battle of Preveza.1539: Hernando de Soto explores inland North America.Main article: 1540sNicolaus Copernicus1540: The Society of Jesus, or the Jesuits, is founded by Ignatius of Loyola and six companions with the approval of Pope Paul III.1540: Sher Shah Suri founds the Suri dynasty in South Asia, an ethnic Pashtun (Pathan) of the house of Sur, who supplanted the Mughal dynasty as rulers of North India during the reign of the relatively ineffectual second Mughal emperor Humayun. Sher Shah Suri decisively defeats Humayun in the Battle of Bilgram (May 17, 1540).1541: Pedro de Valdivia founds Santiago in Chile.1541: An Algerian military campaign by Charles V of Spain (Habsburg) is unsuccessful.1541: Amazon River is encountered and explored by Francisco de Orellana.1541: Capture of Buda and the absorption of the major part of Hungary by the Ottoman Empire.1541: Sahib I Giray of Crimea invades Russia.1542: The Italian War of 15421546 War resumes between Francis I of France and Emperor Charles V. This time Henry VIII is allied with the Emperor, while James V of Scotland and Sultan Suleiman I are allied with the French.1542: Akbar The Great is born in the Rajput Umarkot Fort1542: Spanish explorer Ruy Lpez de Villalobos named the island of Samar and Leyte Las Islas Filipinas honoring Philip II of Spain and became the official name of the archipelago.1543: Ethiopian/Portuguese troops defeat the Adal army led by Imam Ahmad Gurey at the Battle of Wayna Daga; Imam Ahmad Gurey is killed at this battle.1543: Copernicus publishes his theory that the Earth and the other planets revolve around the Sun1543: The Nanban trade period begins after Portuguese traders make contact with Japan.1544: The French defeat an ImperialSpanish army at the Battle of Ceresole.Scenes of everyday life in Ming China, by Qiu Ying1544: Battle of the Shirts in Scotland. The Frasers and Macdonalds of Clan Ranald fight over a disputed chiefship; reportedly, 5 Frasers and 8 Macdonalds survive.1545: Songhai forces sack the Malian capital of Niani1545: The Council of Trent meets for the first time in Trent (in northern Italy).1546: Michelangelo Buonarroti is made chief architect of St. Peter's Basilica.1546: Francis Xavier works among the peoples of Ambon, Ternate and Morotai (Moro) laying the foundations for a permanent mission. (to 1547)1547: Henry VIII dies in the Palace of Whitehall on 28 January at the age of 55.1547: Francis I dies in the Chteau de Rambouillet on 31 March at the age of 52.1547: Edward VI becomes King of England and Ireland on 28 January and is crowned on 20 February at the age of 9.1547: Emperor Charles V decisively dismantles the Schmalkaldic League at the Battle of Mhlberg.1547: Grand Prince Ivan the Terrible is crowned tsar of (All) Russia, thenceforth becoming the first Russian tsar.1548: Battle of Uedahara: Firearms are used for the first time on the battlefield in Japan, and Takeda Shingen is defeated by Murakami Yoshikiyo.1548: Askia Daoud, who reigned from 1548 to 1583, establishes public libraries in Timbuktu (in present-day Mali).1548: The Ming dynasty government of China issues a decree banning all foreign trade and closes down all seaports along the coast; these Hai jin laws came during the Wokou wars with Japanese pirates.1549: Tom de Sousa establishes Salvador in Bahia, north-east of Brazil.1549: Arya Penangsang with the support of his teacher, Sunan Kudus, avenges the death of Raden Kikin by sending an envoy named Rangkud to kill Sunan Prawoto by Keris Kyai Satan Kober (in present-day Indonesia).Main article: 1550sThe Islamic gunpowder empires: Mughal Army artillerymen during the reign of Jalaluddin Akbar1550: The architect Mimar Sinan builds the Sleymaniye Mosque in Istanbul.1550: Mongols led by Altan Khan invade China and besiege Beijing.15501551: Valladolid debate concerning the human rights of the Indigenous people of the Americas.1551: Fifth outbreak of sweating sickness in England. John Caius of Shrewsbury writes the first full contemporary account of the symptoms of the disease.1551: North African pirates enslave the entire population of the Maltese island Gozo, between 5,000 and 6,000, sending them to Libya.1552: Russia conquers the Khanate of Kazan in central Asia.1552: Jesuit China Mission, Francis Xavier dies.1553: Mary Tudor becomes the first queen regnant of England and restores the Church of England under Papal authority.1553: The Portuguese found a settlement at Macau.1554: Missionaries Jos de Anchieta and Manuel da Nbrega establishes So Paulo, southeast Brazil.1554: Princess Elizabeth is imprisoned in the Tower of London upon the orders of Mary I for suspicion of being involved in the Wyatt rebellion.1555: The Muscovy Company is the first major English joint stock trading company.1556: Publication in Venice of Delle Navigiationi et Viaggi (terzo volume) by Giovanni Battista Ramusio, secretary of Council of Ten, with plan La Terra de Hochelaga, an illustration of the Hochelaga.[13]1556: The Shaanxi earthquake in China is history's deadliest known earthquake during the Ming dynasty.1556: Georgius Agricola, the "Father of Mineralogy", publishes his De re metallica.1556: Akbar defeats Hemu at the Second battle of Panipat.1556: Russia conquers the Astrakhan Khanate.15561605: During his reign, Akbar expands the Mughal Empire in a series of conquests (in the Indian subcontinent).Political map of the world in 15561556: Mir Chakar Khan Rind captures Delhi with Humayun.1556: Pomponio Algerio, radical theologian, is executed by boiling in oil as part of the Roman Inquisition.1557: Habsburg Spain declares bankruptcy. Philip II of Spain had to declare four state bankruptcies in 1557, 1560, 1575 and 1596.1557: The Portuguese settle in Macau (on the western side of the Pearl River Delta across from present-day Hong Kong).1557: The Ottomans capture Massawa, all but isolating Ethiopia from the rest of the world.1558: Elizabeth Tudor becomes Queen Elizabeth I at age 25.15581603: The Elizabethan era is considered the height of the English Renaissance.15581583: Livonian War between Poland, Grand Principality of Lithuania, Sweden, Denmark and Russia.1558: After 200 years, the Kingdom of England loses Calais to France.1559: With the Peace of Cateau Cambrsis, the Italian Wars conclude.1559: Sultan Hairun of Ternate (in present-day Indonesia) protests the Portuguese's Christianisation activities in his lands. Hostilities between Ternate and the Portuguese.Main article: 1560sThe Mughal Emperor Akbar shoots the Rajput warrior Jaimal during the Siege of Chittorgarh in 15671560: Ottoman navy defeats the Spanish fleet at the Battle of Djerba.1560: Elizabeth Bathory is born in Nyirbator, Hungary.1560: By winning the Battle of Okehazama, Oda Nobunaga becomes one of the pre-eminent warlords of Japan.1560: Jeanne d'Albret declares Calvinism the official religion of Navarre.1560: Lazarus Church, Macau1561: Sir Francis Bacon is born in London.1561: The fourth battle of Kawanakajima between the Uesugi and Takeda at Hachimanbara takes place.1561: Guido de Bres draws up the Belgic Confession of Protestant faith.1562: Mughal emperor Akbar reconciles the Muslim and Hindu factions by marrying into the powerful Rajput Hindu caste.15621598: French Wars of Religion between Catholics and Huguenots.1562: Massacre of Wassy and Battle of Dreux in the French Wars of Religion.1562: Portuguese Dominican priests build a palm-trunk fortress which Javanese Muslims burned down the following year. The fort was rebuilt from more durable materials and the Dominicans commenced the Christianisation of the local population.[12]1563: Plague outbreak claimed 80,000 people in Elizabethan England. In London alone, over 20,000 people died of the disease.1564: Galileo Galilei born on February 151564: William Shakespeare baptized 26 April1565: Deccan sultanates defeat the Vijayanagara Empire at the Battle of Talikota.1565: Mir Chakar Khan Rind dies at aged 97.1565: Estcio de S establishes Rio de Janeiro in Brazil.1565: The Hospitallers, a Crusading Order, defeat the Ottoman Empire at the siege of Malta (1565).1565: Miguel Lpez de Legazpi establishes in Cebu the first Spanish settlement in the Philippines starting a period of Spanish colonization that would last over three hundred years.1565: Spanish navigator Andres de Urdaneta discovers the maritime route from Asia to the Americas across the Pacific Ocean, also known as the tornaviaje.1565: Royal Exchange is founded by Thomas Gresham.1566: Suleiman the Magnificent, ruler of the Ottoman Empire, dies on September 7, during the battle of Szigetvar.Siege of Valenciennes during the Dutch War of Independence in 156715661648: Eighty Years' War between Spain and the Netherlands.1566: Da le Balle Contrade d'Oriente, composed by Cipriano de Rore.1567: After 45 years' reign, Jiajing Emperor died in the Forbidden City, Longqing Emperor ascended the throne of Ming dynasty.1567: Mary, Queen of Scots, is imprisoned by Elizabeth I.1568: The Transylvanian Diet, under the patronage of the prince John Sigismund Zpolya, the former king of Hungary, inspired by the teachings of Ferenc Dvid, the founder of the Unitarian Church of Transylvania, promulgates the Edict of Torda, the first law of freedom of religion and of conscience in the World.15681571: Morisco Revolt in Spain.15681600: The Azuchi-Momoyama period in Japan.1568: Hadiwijaya sent his adopted son and son in-law Sutawijaya, who would later become the first ruler of the Mataram dynasty of Indonesia, to kill Arya Penangsang.1569: Rising of the North in England.1569: Mercator 1569 world map published by Gerardus Mercator.1569: The PolishLithuanian Commonwealth is created with the Union of Lublin which lasts until 1795.1569: Peace treaty signed by Sultan Hairun of Ternate and Governor Lopez De Mesquita of Portugal.Main article: 1570sThe Battle of Lepanto1570: Ivan the Terrible, tsar of Russia, orders the massacre of inhabitants of Novgorod.1570: Pope Pius V issues Regnans in Excelsis, a papal bull excommunicating all who obeyed Elizabeth I and calling on all Catholics to rebel against her.1570: Sultan Hairun of Ternate (in present-day Indonesia) is killed by the Portuguese.[12] Babullah becomes the next Sultan.1570: 20,000 inhabitants of Nicosia in Cyprus were massacred and every church, public building, and palace was looted. Cyprus fell to the Ottoman Turks the following year.1571: Pope Pius V completes the Holy League as a united front against the Ottoman Turks, responding to the fall of Cyprus to the Ottomans.1571: The Spanish-led Holy League navy destroys the Ottoman Empire navy at the Battle of Lepanto.1571: Crimean Tatars attack and sack Moscow, burning everything but the Kremlin.1571: American Indians kill Spanish missionaries in what would later be Jamestown, Virginia.1571: Spanish conquistador Miguel Lpez de Legazpi establishes Manila, Philippines as the capital of the Spanish East Indies.1572: Brielle is taken from Habsburg Spain by Protestant Watergeuzen in the Capture of Brielle, in the Eighty Years' War.1572: Spanish conquistadores apprehend the last Inca leader Tupak Amaru at Vilcabamba, Peru, and execute him in Cuzco.1572: Jeanne d'Albret dies aged 43 and is succeeded by Henry of Navarre.1572: Catherine de' Medici instigates the St. Bartholomew's Day massacre which takes the lives of Protestant leader Gaspard de Coligny and thousands of Huguenots. The violence spreads from Paris to other cities and the countryside.1572: First edition of the epic The Lusiads of Lus Vaz de Cames, three years after the author returned from the East.[14]1572: The 9 years old Taizi, Zhu Yijun ascended the throne of Ming dynasty, known as Wanli Emperor.1573: After heavy losses on both sides the siege of Haarlem ends in a Spanish victory.St. Bartholomew's Day massacre of French Protestants1574: in the Eighty Years' War the capital of Zeeland, Middelburg declares for the Protestants.1574: After a siege of 4 months the siege of Leiden ends in a comprehensive Dutch rebel victory.1575: Oda Nobunaga finally captures Nagashima fortress.1575: Following a five-year war, the Ternateans under Sultan Babullah defeated the Portuguese.1576: Tahmasp I, Safavid shah, dies.1576: The Battle of Haldighati is fought between the ruler of Mewar, Maharana Pratap and the Mughal Empire's forces under Emperor Akbar led by Raja Man Singh.1576: Sack of Antwerp by badly paid Spanish soldiers.15771580: Francis Drake circles the world.1577: Ki Ageng Pemanahan built his palace in Pasargede or Kotagede.1578: King Sebastian of Portugal is killed at the Battle of Alcazarquivir.1578: The Portuguese establish a fort on Tidore but the main centre for Portuguese activities in Maluku becomes Ambon.[12]1578: Sonam Gyatso is conferred the title of Dalai Lama by Tumed Mongol ruler, Altan Khan. Recognised as the reincarnation of two previous Lamas, Sonam Gyatso becomes the third Dalai Lama in the lineage.[15]1578: Governor-General Francisco de Sande officially declared war against Brunei in 1578, starting the Castilian War of 1578.1579: The Union of Utrecht unifies the northern Netherlands, a foundation for the later Dutch Republic.1579: The Union of Arras unifies the southern Netherlands, a foundation for the later states of the Spanish Netherlands, the Austrian Netherlands and Belgium.The Irish Gaelic chieftain's feast, from The Image of Ireland1579: The British navigator Sir Francis Drake passes through Maluku and transit in Ternate on his circumnavigation of the world. The Portuguese establish a fort on Tidore but the main centre for Portuguese activities in Maluku becomes Ambon.[16]Main article: 1580sThe fall of Spanish Armada1580: Drake's royal reception after his attacks on Spanish possessions influences Philip II of Spain to build up the Spanish Armada. English ships in Spanish harbours are impounded.1580: Spain unifies with Portugal under Philip II. The struggle for the throne of Portugal ends the Portuguese Empire. The Spanish and Portuguese crowns are united for 60 years, i.e. until 1640.15801587: Nagasaki comes under control of the Jesuits.1581: Dutch Act of Abjuration, declaring abjuring allegiance to Philip II of Spain.1581: Bayinnaung dies at the age of 65.1582: Oda Nobunaga commits seppuku during the Honn-ji Incident coup by his general, Akechi Mitsuhide.1582: Pope Gregory XIII issues the Gregorian calendar. The last day of the Julian calendar was Thursday, 4 October 1582 and this was followed by the first day of the Gregorian calendar, Friday, 15 October 15821582: Yermak Timofeyevich conquers the Siberia Khanate on behalf of the Stroganovs.1583: Denmark builds the world's first theme park, Bakken.1583: Death of Sultan Babullah of Ternate.15841585: After the siege of Antwerp, many of its merchants flee to Amsterdam. According to Luc-Normand Tellier, "At its peak, between 1510 and 1557, Antwerp concentrated about 40% of the world trade...It is estimated that the port of Antwerp was earning the Spanish crown seven times more revenues than the Americas."[17]1584: Ki Ageng Pemanahan died. Sultan Pajang raised Sutawijaya, son of Ki Ageng Pemanahan as the new ruler in Mataram, titled "Loring Ngabehi Market" (because of his home in the north of the market).1585: Akbar annexes Kashmir and adds it to the Kabul SubahPortuguese fusta in India from a book by Jan Huygen van Linschoten1585: Colony at Roanoke founded in North America.15851604: The Anglo-Spanish War is fought on both sides of the Atlantic.1587: Mary, Queen of Scots is executed by Elizabeth I.1587: The reign of Abbas I marks the zenith of the Safavid dynasty.1587: Troops that would invade Pajang Mataram Sultanate storm ravaged the eruption of Mount Merapi. Sutawijaya and his men survived.1588: Mataram into the kingdom with Sutawijaya as Sultan, titled "Senapati Ingalaga Sayidin Panatagama" means the warlord and cleric Manager Religious Life.1588: England repulses the Spanish Armada.1589: Spain repulses the English Armada.1589: Catherine de' Medici dies at aged 69.Main articles: 1590s and 1600sAbu'l-Fazl ibn Mubarak presenting Akbarnama to Mughal Azam Akbar, Mughal miniature1590: Siege of Odawara: the Go-Hojo clan surrender to Toyotomi Hideyoshi, and Japan is unified.1591: Gazi Giray leads a huge Tatar expedition against Moscow.1591: In Mali, Moroccan forces of the Sultan Ahmad al-Mansur led by Judar Pasha defeat the Songhai Empire at the Battle of Tondibi.15921593: John Stow reports 10,675 plague deaths in London, a city of approximately 200,000 people.15921598: Korea, with the help of Ming dynasty China, repels two Japanese invasions.15931606: The Long War between the Habsburg monarchy and the Ottoman Turks.1594: St. Paul's College, Macau, founded by Alessandro Valignano.1595: First Dutch expedition to Indonesia sets sail for the East Indies with two hundred and forty-nine men and sixty-four cannons led by Cornelis de Houtman.[18]1596: Birth of Ren Descartes.1596: June, de Houtman's expedition reaches Banten the main pepper port of West Java where they clash with both the Portuguese and Indonesians. It then sails east along the north coast of Java losing twelve crew to a Javanese attack at Sidayu and killing a local ruler in Madura.[18]1597: Romeo and Juliet is published.1597: Cornelis de Houtman's expedition returns to the Netherlands with enough spices to make a considerable profit.[18]1598: The Edict of Nantes ends the French Wars of Religion.1598: Abbas I moves Safavids capital from Qazvin to Isfahan in 1598.15981613: Russia descends into anarchy during the Time of Troubles.1598: The Portuguese require an armada of 90 ships to put down a Solorese uprising.[12] (to 1599)1598: More Dutch fleets leave for Indonesia and most are profitable.[18]Edo period screen depicting the Battle of Sekigahara1598: The province of Santa Fe de Nuevo Mxico is established in Northern New Spain. The region would later become a territory of Mexico, the New Mexico Territory in the United States, and the US State of New Mexico.1598: Death of Toyotomi Hideyoshi, known as the unifier of Japan.1599: The Mali Empire is defeated at the Battle of Jenn.1599: The van Neck expedition returns to Europe. The expedition makes a 400 per cent profit.[18] (to 1600)1599: March, Leaving Europe the previous year, a fleet of eight ships under Jacob van Neck was the first Dutch fleet to reach the Spice Islands of Maluku.[18]1600: Giordano Bruno is burned at the stake for heresy in Rome.Siege of Fiakovo castle during the Long Turkish War1600: Battle of Sekigahara in Japan. End of the Warring States period and beginning of the Edo period.1600: The Portuguese win a major naval battle in the bay of Ambon.[19] Later in the year, the Dutch join forces with the local Hituese in an anti-Portuguese alliance, in return for which the Dutch would have the sole right to purchase spices from Hitu.[19]1600: Elizabeth I grants a charter to the British East India Company beginning the English advance in Asia.1600: Michael the Brave unifies the three principalities: Wallachia, Moldavia and Transylvania after the Battle of elimbr from 1599.For later events, see Timeline of the 17th century.Polybius' The Histories translated into Italian, English, German and French.[20]Mississippian culture disappears.Medallion rug, variant Star Ushak style, Anatolia (modern Turkey), is made. It is now kept at the Saint Louis Art Museum.Hernan Cortes (14851547)Henry VIII, (14911547) King of England and IrelandDon Fernando lvarez de Toledo (15071582)Suleiman the Magnificent, Sultan of the Ottoman Empire (15201566)Ivan IV the Terrible (15301584)Oda Nobunaga (15341582)Sir Francis Drake (c. 1540 1596)Alberico Gentili, (15521608) the Father of international lawPhilip II of Spain, King of Spain (15561598)Akbar the Great, Mughal emperor (15561605)Related article: List of 16th century inventions.The Columbian Exchange introduces many plants, animals and diseases to the Old and New Worlds.Introduction of the spinning wheel revolutionizes textile production in Europe.The letter J is introduced into the English alphabet.1500: First portable watch is created by Peter Henlein of Germany.The Iberian Union in 1598, under Philip II, King of Spain and Portugal1513: Juan Ponce de Len sights Florida and Vasco Nez de Balboa sights the eastern edge of the Pacific Ocean.15191522: Ferdinand Magellan and Juan Sebastin Elcano lead the first circumnavigation of the world.15191540: In America, Hernando de Soto expeditions map the Gulf of Mexico coastline and bays.1525: Modern square root symbol ()1540: Francisco Vsquez de Coronado sights the Grand Canyon.154142: Francisco de Orellana sails the length of the Amazon River.154243: Firearms are introduced into Japan by the Portuguese.1543: Copernicus publishes his theory that the Earth and the other planets revolve around the Sun1545: Theory of complex numbers is first developed by Gerolamo Cardano of Italy.1558: Camera obscura is first used in Europe by Giambattista della Porta of Italy.15591562: Spanish settlements in Alabama/Florida and Georgia confirm dangers of hurricanes and local native warring tribes.1565: Spanish settlers outside New Spain (Mexico) colonize Florida's coastline at St. Augustine.1565: Invention of the graphite pencil (in a wooden holder) by Conrad Gesner. Modernized in 1812.1568: Gerardus Mercator creates the first Mercator projection map.1572: Supernova SN 1572 is observed by Tycho Brahe in the Milky Way.1582: Gregorian calendar is introduced in Europe by Pope Gregory XIII and adopted by Catholic countries.c. 1583: Galileo Galilei of Pisa, Italy identifies the constant swing of a pendulum, leading to development of reliable timekeepers.1585: earliest known reference to the 'sailing carriage' in China.1589: William Lee invents the stocking frame.1591: First flush toilet is introduced by Sir John Harrington of England, the design published under the title 'The Metamorphosis of Ajax'.1593: Galileo Galilei invents a thermometer.1596: William Barents discovers Spitsbergen.1597: Opera in Florence by Jacopo Peri.Entertainment in the 16th century^ a b Modern reference works on the period tend to follow the introduction of the Gregorian calendar for the sake of clarity; thus NASA's lunar eclipse catalogue states "The Gregorian calendar is used for all dates from 1582 Oct 15 onwards. 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An Encyclopedia of World History (5th ed. 1973); highly detailed outline of events online free Media related to 16th century at Wikimedia CommonsTimelines of 16th century events, science, culture and personsRetrieved from " 4The following pages link to 16th century External tools(link counttransclusion countsorted list) See help page for transcluding these entriesShowing 50 items.View (previous 50 | next 50) (20 | 50 | 100 | 250 | 500)Bagpipes (links | edit)List of decades, centuries, and millennia (links | edit)Fashion (links | edit)Giovanni Boccaccio (links | edit)History of Mali (links | edit)History of Mauritius (links | edit)Post office (links | edit)Snare drum (links | edit)Republican Party (United States) (links | edit)20th century (links | edit)15th century (links | edit)17th century (links | edit)18th century (links | edit)1624 (links | edit)1626 (links | edit)1642 (links | edit)1661 (links | edit)1608 (links | edit)1492 (links | edit)14th century (links | edit)1st century (links | edit)13th century (links | edit)4th century (links | edit)12th century (links | edit)11th century (links | edit)1564 (links | edit)1648 (links | edit)1572 (links | edit)1623 (links | edit)1662 (links | edit)1490s (links | edit)1640s (links | edit)1597 (links | edit)1690 (links | edit)1688 (links | edit)7th century (links | edit)10th century (links | edit)9th century (links | edit)8th century (links | edit)6th century (links | edit)5th century (links | edit)3rd century (links | edit)2nd century (links | edit)1573 (links | edit)1570s (links | edit)1574 (links | edit)1436 (links | edit)1476 (links | edit)1542 (links | edit)1540s (links | edit)View (previous 50 | next 50) (20 | 50 | 100 | 250 | 500)Retrieved from " WhatLinksHere/16th_century" by Chris Woodford. Last updated: May 12, 2023. Which is bettercomputer or brain? Ask most people if they want a brain like a computer and they'd probably jump at the chance. But look at the kind of work scientists have been doing over the last couple of decades and you'll find many of them have been trying hard to make their computers more like brains! How? With the help of neural networkscomputer programs assembled from hundreds, thousands, or millions of artificial brain cells that learn and behave in a remarkably similar way to human brains. What exactly are neural networks? How do they work? Let's take a closer look! Photo: Computers and brains have much in common, but they're essentially very different. What happens if you combine the best of both worldsthe systematic power of a computer and the densely interconnected cells of a brain? You get a superbly useful neural

network. Contents You often hear people comparing the human brain and the electronic computer and, on the face of it, they do have things in common. A typical brain contains something like 100 billion minuscule cells called neurons (no-one knows exactly how many there are and estimates go from about 50 billion to as many as 500 billion).[1] Each neuron is made up of a cell body (the central mass of the cell) with a number of connections coming off it: numerous dendrites (the cell's inputscarrying information toward the cell body) and a single axon (the cell's outputcarrying information away). Neurons are so tiny that you could pack about 100 of their cell bodies into a single millimeter. (It's also worth noting, briefly in passing, that neurons make up only 1050 percent of all the cells in the brain; the rest are glial cells, also called neuroglia, that support and protect the neurons and feed them with energy that allows them to work and grow.) [1] Inside a computer, the equivalent to a brain cell is ananoscopically tiny switching device called a transistor. The latest, cutting-edge microprocessors (single-chip computers) contain over 50 billion transistors; even a basic Pentium microprocessorfrom about 20 years ago had about 50 million transistors, all packed onto an integrated circuit just 25mm square (smaller than a postage stamp)! [2] Artwork: A neuron: the basic structure of a brain cell, showing the central cell body, the dendrites (leading into the cell body), and the axon (leading away from it). That's where the comparison between computers and brains begins and ends, because the two things are completely different. It's not just that computers are cold metal boxes stuffed full of binary numbers, while brains are warm, living, things packed with thoughts, feelings, and memories. The real difference is that computers and brains "think" in completely different ways. The transistors in a computer are wired in relatively simple, serial chains (each one is connected to maybe two or three others in basic arrangements known as logic gates), whereas the neurons in a brain are densely interconnected in complex, parallel ways (each one is connected to perhaps 10,000 of its neighbors). [3] This essential structural difference between computers (with maybe a few hundred million transistors connected in a relatively simple way) and brains (perhaps 10100 times more brain cells connected in richer and more complex ways) is what makes them "think" so very differently. Computers are perfectly designed for storing vast amounts of meaningless (to them) information and rearranging it in any number of ways according to precise instructions (programs) we feed into them in advance. Brains, on the other hand, learn slowly, by a more roundabout method, often taking months or years to make complete sense of something really complex. But, unlike computers, they can spontaneously put information together in astounding new waysthat's where the human creativity of a Beethoven or a Shakespeare comes fromrecognizing original patterns, forging connections, and seeing the things they've learned in a completely different light. Wouldn't it be great if computers were more like brains? That's where neural networks come in!Photo: Electronic brain? Not quite. Computer chips are made from thousands, millions, and sometimes even billions of tiny electronic switches called transistors. That sounds like a lot, but there are still far fewer of them than there are cells in the human brain. What is a neural network? The basic idea behind a neural network is to simulate (copy in a simplified but reasonably faithful way) lots of densely interconnected brain cells inside a computer so you can get it to learn things, recognize patterns, and make decisions in a humanlike way. The amazing thing about a neural network is that you don't have to program it to learn explicitly: it learns all by itself, just like a brain! But it isn't a brain. It's important to note that neural networks are (generally) software simulations: they're made by programming very ordinary computers, working in a very traditional fashion with their ordinary transistors and serially connected logic gates, to behave as though they're built from billions of highly interconnected brain cells working in parallel. No-one has yet attempted to build a computer by wiring up transistors in a densely parallel structure exactly like the human brain. In other words, a neural network differs from a human brain in exactly the same way that a computer model of the weather differs from real clouds, snowflakes, or sunshine. Computer simulations are just collections of algebraic variables and mathematical equations linking them together (in other words, numbers stored in boxes whose values are constantly changing). They mean nothing whatsoever to the computers they run insideonly to the people who program them. Real and artificial neural networksBefore we go any further, it's also worth noting some jargon. Strictly speaking, neural networks produced this way are called artificial neural networks (or ANNs) to differentiate them from the real neural networks (collections of interconnected brain cells) we find inside our brains. You might also see neural networks referred to by names like connectionist machines (the field is also called connectionism), parallel distributed processors (PDP), thinking machines, and so onbut in this article we're going to use the term "neural network" throughout and always use it to mean "artificial neural network." What does a neural network consist of? A typical neural network has anything from a few dozen to hundreds, thousands, or even millions of artificial neurons calledunits arranged in a series of layers, each of which connects to the layers on either side. Some of them, known as input units, are designed to receive various forms of information from the outside world that the network will attempt to learn about, recognize, or otherwise process. Other units sit on the opposite side of the network and signal how it responds to the information it's learned; those are known as output units. In between the input units and output units are one or more layers of hidden units, which, together, form the majority of the artificial brain. Most neural networks are fully connected, which means each hidden unit and each output unit is connected to every unit in the layers either side. The connections between one unit and another are represented by a number called a weight, which can be either positive (if one unit excites another) or negative (if one unit suppresses or inhibits another). The higher the weight, the more influence one unit has on another. (This corresponds to the way actual brain cells trigger one another across tiny gaps called synapses.) Photo: A fully connected neural network is made up of input units (red), hidden units (blue), and output units (yellow), with all the units connected to all the units in the layers either side. Inputs are fed in from the left, activate the hidden units in the middle, and make outputs feed out from the right. The strength (weight) of the connection between any two units is gradually adjusted as the network learns. Deep neural networks Although a simple neural network for simple problem solving could consist of just three layers, as illustrated here, it could also consist of many different layers between the input and the output. A richer structure like this is called a deep neural network (DNN), and it's typically used for tackling much more complex problems. In theory, a DNN can map any kind of input to any kind of output, but the drawback is that it needs considerably more training: it needs to "see" millions or billions of examples compared to perhaps the hundreds or thousands that a simpler network might need. Deep or "shallow," however it's structured and however we choose to illustrate it on the page, it's worth reminding ourselves, once again, that a neural network is not actually a brain or anything brain like. Ultimately, it's a bunch of clever math... a load of equations... an algorithm, if you prefer. [4] Other types of neural networks Most neural networks are designed upfront to solve a particular problem. So they're designed, built, and trained on masses of data, and then they spend the rest of their days processingsimilar data, and churning out solutions to essentially the same problem, over and over again. But human brains don't really work that way: we're much more adaptable to the ever-changing world around us. Liquid neural networks (LNN) are ones that replicate this adaptibility, to an extent, by modifying their algorithms and equations to suit their environments. How does a neural network learn things? Information flows through a neural network in two ways. When it's learning (being trained) or operating normally (after being trained), patterns of information are fed into the network via the input units, which trigger the layers of hidden units, and these in turn arrive at the output units. This common design is called a feedforward network. Not all units "fire" all the time. Each unit receives inputs from the units to its left, and the inputs are multiplied by the weights of the connections they travel along. Every unit adds up all the inputs it receives in this way and (in the simplest type of network) if the sum is more than a certain threshold value, the unit "fires" and triggers the units it's connected to (those on its right). Photo: Bowling: You learn how to do skillful things like this with the help of the neural network inside your brain. Every time you throw the ball wrong, you learn what corrections you need to make next time. Photo by Kenneth R. Hendrix/US Navypublished on Flickr. For a neural network to learn, there has to be an element of feedback involvedjust as children learn by being told what they're doing right or wrong. In fact, we all use feedback, all the time. Think back to when you first learned to play a game like ten-pin bowling. As you picked up the heavy ball and rolled it down the alley, your brain watched how quickly the ball moved and the line it followed, and noted how close you came to knocking down the skittles. Next time it was your turn, you remembered what you'd done wrong before, modified your movements accordingly, and hopefully threw the ball a bit better. So you used feedback to compare the outcome you wanted with what actually happened, figured out the difference between the two, and used that to change what you did next time ("I need to throw it harder," "I need to roll slightly more to the left," "I need to let go later," and so on). The bigger the difference between the intended and actual outcome, the more radically you would have altered your moves. Neural networks learn things in exactly the same way, typically by a feedback process called backpropagation (sometimes abbreviated as "backprop"). This involves comparing the output a network produces with the output it was meant to produce, and using the difference between them to modify the weights of the connections between the units in the network, working from the output units through the hidden units to the input unitsgoing backward, in other words. In time, backpropagation causes the network to learn, reducing the difference between actual and intended output to the point where the two exactly coincide, so the network figures things out exactly as it should. Artwork: A neural network can learn by backpropagation, which is a kind of feedback process that passes corrective values backward through the network. Simple neural networks use simple math: they use basic multiplication to weight the connections between different units. Some neural networks learn to recognize patterns in data using more complex and elaborate math. Known as convolutional neural networks (CNNs or, sometimes, "ConvNets") their input layers take in 2D or 3D "tables" of data (like the matrices you might remember learning about in school). Their hidden layers (sometimes several dozen of them) include some that perform a mathematical process called convolution. Simply speaking, convolutional layers recognize significant patterns hidden in data and "concentrate" them into an easier-to-use form. Essentially, they're detecting key features, which can then be classified by further layers that work like a more traditional neural network. CNNs are particularly good at classifying images or videos, recognizing handwriting, and so on. Artwork: This convolutional neural network (greatly simplified) extracts and emphasizes key features (by the mathematical process of convolutionbroadly a kind of matrix multiplication). These are fed into a more conventional neural network, which uses them to recognize an unknown object or image. How does it work in practice? Once the network has been trained with enough learning examples, it reaches a point where you can present it with an entirely new set of inputs it's never seen before and see how it responds. For example, suppose you've been teaching a network by showing it lots of pictures of chairs and tables, represented in some appropriate way it can understand, and telling it whether each one is a chair or a table. After showing it, let's say, 25 different chairs and 25 different tables, you feed it a picture of some new design it's not encountered beforelet's say a chaise longueand see what happens. Depending on how you've trained it, it'll attempt to categorize the new example as either a chair or a table, generalizing on the basis of its past experiencejust like a human. Hey presto, you've taught a computer how to recognize furniture! That doesn't mean to say a neural network can just "look" at pieces of furniture and instantly respond to them in meaningful ways; it's not behaving like a person. Consider the example we've just given: the network is not actually looking at pieces of furniture. The inputs to a network are essentially binary numbers: each input unit is either switched on or switched off. So if you had five input units, you could feed in information about five different characteristics of different chairs using binary (yes/no) answers. The questions might be 1) Does it have a back? 2) Does it have a top? 3) Does it have soft upholstery? 4) Can you sit on it comfortably for long periods of time? 5) Can you put lots of things on top of it? A typical chair would then present as Yes, No, Yes, Yes, No or 10110 in binary, while a typical table might be No, Yes, No, No, Yes or 01001. So, during the learning phase, the network is simply looking at lots of numbers like 10110 and 01001 and learning that some mean chair (which might be an output of 1) while others mean table (an output of 0). What are neural networks used for? Photo: For the last two decades, NASA has been experimenting with a self-learning neural network calledIntelligent Flight Control System (IFCS) that can help pilots land planes after suffering major failures or damage in battle. The prototype was tested on this modified NF-15B plane (a relative of the McDonnell Douglas F-15). Photo by Jim Ross courtesy of NASA. On the basis of this example, you can probably see lots of different applications for neural networks that involve recognizing patterns and making simple decisions about them. In airplanes, you might use a neural network as a basic autopilot, with input units reading signals from the various cockpit instruments and output units modifying the plane's controls appropriately to keep it safely on course. Inside a factory, you could use a neural network for quality control. Let's say you're producing clothes washing detergent in some giant, convoluted chemical process. You could measure the final detergent in various ways (its color, acidity, thickness, or whatever), feed those measurements into your neural network as inputs, and then have the network decide whether to accept or reject the batch. There are lots of applications for neural networks in security, too. Suppose you're running a bank with many thousands of credit-card transactions passing through your computer system every single minute. You need a quick automated way of identifying any transactions that might be fraudulentand that's something for which a neural network is perfectly suited. Your inputs would be things like 1) Is the cardholder actually present? 2) Has a valid PIN number been used? 3) Have five or more transactions been presented with this card in the last 10 minutes? 4) Is the card being used in a different country from which it's registered? and so on. With enough clues, a neural network can flag up any transactions that look suspicious, allowing a human operator to investigate them more closely. In a very similar way, a bank could use a neural network to help it decide whether to give loans to people on the basis of their past credit history, current earnings, and employment record. Photo: Handwriting recognition on a touchscreen, tablet computer is one of many applications perfectly suited to a neural network. Each character (letter, number, or symbol) that you write is recognized on the basis of key features it contains (vertical lines, horizontal lines, angled lines, curves, and so on) and the order in which you draw them on the screen. Neural networks get better and better at recognizing over time. Many of the things we all do everyday involve recognizing patterns and using them to make decisions, so neural networks can help us out in zillions of different ways. They can help us forecast the stockmarket or the weather, operate radar scanning systems that automatically identify enemy aircraft or ships, and even help doctors to diagnose complex diseases on the basis of their symptoms. There might be neural networks ticking away inside your computer or your cellphone right this minute. If you use cellphone apps that recognize your handwriting on a touchscreen, they might be using a simple neural network to figure out which characters you're writing by looking out for distinct features in the marks you make with your fingers (and the order in which you make them). Some kinds of voice recognition software also use neural networks. And so do some of the email programs that automatically differentiate between genuine emails and spam.Neural networks have even proved effective in translating text from one language to another. Google's automatic translation, for example, has made increasing use of this technology over the last few years to convert words in one language (the network's input) into the equivalent words in another language (the network's output). In 2016, Google announced it was using something it called Neural Machine Translation (NMT) to convert entire sentences, instantly, with a5585 percent reduction in errors. This is just one example of how Google deploys neural-network technology: Google Brainis the name it's given to a massive research effort that applies neural techniques across its whole range of products, including its search engine. It also uses deep neural networks to power the recommendations you see on YouTube, with models that "learn approximatelyone billion parameters and are trained on hundreds of billions of examples." [5] All in all, neural networks have made computer systems more useful by making them more human. So next time you think you might like your brain to be as reliable as a computer, think againand be grateful you have such a superb neural network already installed in your head! Chris Woodford is the author and editor of dozens of science and technology books for adults and children, including DK's worldwide bestselling Cool Stuff series and Atoms Under the Floorboards, which won the American Institute of Physics Science Writing award in 2016. You can hire him to write books, articles, scripts, corporate copy, and more via his website chriswoodford.com. Contents Neural Network Definition Neural networks are a set of algorithms, modeled loosely after the human brain, that are designed to recognize patterns. They interpret sensory data through a kind of machine perception, labeling or clustering raw input. The patterns they recognize are numerical, contained in vectors, into which all real-world data, be it images, sound, text or time series, must be translated. Neural networks help us cluster and classify. You can think of them as a clustering and classification layer on top of the data you store and manage. They help to group unlabeled data according to similarities among the example inputs, and they classify data when they have a labeled dataset to train on. (Neural networks can also extract features that are fed to other algorithms for clustering and classification; so you can think of deep neural networks as components of larger machine-learning applications involving algorithms for reinforcement learning, classification and regression.) Artificial neural networks are the foundation of large-language models (LLMs) used by chatGPT, Microsofts Bing, Googles Bard and Metas Llama, among others. What kind of problems does deep learning solve, and more importantly, can it solve yours? To know the answer, you need to ask a few questions: What outcomes do I care about? In a classification problem, those outcomes are labels that could be applied to data: for example, spam or not_spam in an email filter, good_guy or bad_guy in fraud detection, angry_customer or happy_customer in customer relationship management. Other types of problems include anomaly detection (useful in fraud detection and predictive maintenance of manufacturing equipment), and clustering, which is useful in recommendation systems that surface similarities. Do I have the right data? For example, if you have a classification problem, youll need labeled data. Is the dataset you need publicly available, or can you create it (with a data annotation service like Scale or AWS Mechanical Turk)? In this example, spam emails would be labeled as spam, and the labels would enable the algorithm to map from inputs to the classifications you care about. You cant know that you have the right data until you get your hands on it. If you are a data scientist working on a problem, you cant trust anyone to tell you whether the data is good enough. Only direct exploration of the data will answer this question. Find Out How Page One Can Support You Get Started Deep learning maps inputs to outputs. It finds correlations. It is known as a universal approximator, because it can learn to approximate an unknown function $f(x) = y$ between any input x and any output y, assuming they are related at all (by correlation or causation, for example). In the process of learning, a neural network finds the right f, or the correct manner of transforming x into y, whether that be $f(x) = 3x + 12$ or $f(x) = 9x - 0.1$. Here are a few examples of what deep learning can do. Classification All classification tasks depend upon labeled datasets; that is, humans must transfer their knowledge to the dataset in order for a neural network to learn the correlation between labels and data. This is known as supervised learning. Detect faces, identify people in images, recognize facial expressions (angry, joyful) Identify objects in images (stop signs, pedestrians, lane markers) Recognize gestures in video Detect voices, identify speakers, transcribe speech to text, recognize sentiment in voices Classify text as spam (in emails), or fraudulent (in insurance claims); recognize sentiment in text (customer feedback) Any labels that humans can generate, any outcomes that you care about and which correlate to data, can be used to train a neural network. Clustering Clustering or grouping is the detection of similarities. Deep learning does not require labels to detect similarities. Learning without labels is called unsupervised learning. Unlabeled data is the majority of data in the world. One law of machine learning is: the more data an algorithm can train on, the more accurate it will be. Therefore, unsupervised learning has the potential to produce highly accurate models. Search: Comparing documents, images or sounds to surface similar items. Anomaly detection: The flipside of detecting similarities is detecting anomalies, or unusual behavior. In many cases, unusual behavior correlates highly with things you want to detect and prevent, such as fraud. Predictive Analytics: Regressions With classification, deep learning is able to establish correlations between, say, pixels in an image and the name of a person. You might call this a static prediction. By the same token, exposed to enough of the right data, deep learning is able to establish correlations between present events and future events. It can run regression between the past and the future. The future event is like the label in a sense. Deep learning doesnt necessarily care about time, or the fact that something hasnt happened yet. Given a time series, deep learning may read a string of number and predict the number most likely to occur next. Hardware breakdowns (data centers, manufacturing, transport) Health breakdowns (strokes, heart attacks based on vital stats and data from wearables) Customer churn (predicting the likelihood that a customer will leave, based on web activity and metadata) Employee turnover (ditto, but for employees) The better we can predict, the better we can prevent and pre-empt. As you can see, with neural networks, were moving towards a world of fewer surprises. Not zero surprises, just marginally fewer. Were also moving toward a world of smarter agents that combine neural networks with other algorithms like reinforcement learning to attain goals. With that brief overview of deep learning use cases, lets look at what neural nets are made of. Neural Network Elements Deep learning is the name we use for stacked neural networks; that is, networks composed of several layers. The layers are made of nodes. A node is just a place where computation happens, loosely patterned on a neuron in the human brain, which fires when it encounters sufficient stimuli. A node combines input from the data with a set of coefficients, or weights, that either amplify or dampen that input, thereby assigning significance to inputs with regard to the task the algorithm is trying to learn; e.g. which input is most helpful is classifying data without error? These input-weight products are summed and then the sum is passed through a nodes so-called activation function, to determine whether and to what extent that signal should progress further through the network to affect the ultimate outcome, say, an act of classification. If the signals passes through, the neuron has been activated. Heres a diagram of what one node might look like. A node layer is a row of those neuron-like switches that turn on or off as the input is fed through the net. Each layers output is simultaneously the subsequent layers input, starting from an initial input layer receiving your data. Pairing the models adjustable weights with input features is how we assign significance to those features with regard to how the neural network classifies and clusters input. Key Concepts of Deep Neural Networks Deep-learning networks are distinguished from the more commonplace single-hidden-layer neural networks by their depth; that is, the number of node layers through which data must pass in a multistep process of pattern recognition. Earlier versions of neural networks such as the first perceptrons were shallow, composed of one input and one output layer, and at most one hidden layer in between. More than three layers (including input and output) qualifies as deep learning. So deep is not just a buzzword to make algorithms seem like they read Sartre and listen to bands you havent heard of yet. It is a strictly defined term that means more than one hidden layer. In deep-learning networks, each layer of nodes trains on a distinct set of features based on the previous layers output. The further you advance into the neural net, the more complex the features your nodes can recognize, since they aggregate and recombine features from the previous layer. This is known as feature hierarchy, and it is a hierarchy of increasing complexity and abstraction. It makes deep-learning networks capable of handling very large, high-dimensional data sets with billions of parameters that pass through nonlinear functions. Above all, these neural nets are capable of discovering latent structures within unlabeled, unstructured data, which is the vast majority of data in the world. Another word for unstructured data is raw media; i.e. pictures, texts, video and audio recordings. Therefore, one of the problems deep learning solves best is in processing and clustering the worlds raw, unlabeled media, discerning similarities and anomalies in data that no human has organized in a relational database or ever put a name to. For example, deep learning can take a million images, and cluster them according to their similarities: cats in one corner, ice breakers in another, and in a third all the photos of your grandmother. This is the basis of so-called smart photo albums. Now apply that same idea to other data types: Deep learning might cluster raw text such as emails or news articles. Emails full of angry complaints might cluster in one corner of the vector space, while satisfied customers, or spambot messages, might cluster in others. This is the basis of various messaging filters, and can be used in customer-relationship management (CRM). The same applies to voice messages. With time series, data might cluster around normal/healthy behavior and anomalous/dangerous behavior. If the time series data is being generated by a smart phone, it will provide insight into users health and habits; if it is being generated by an autopart, it might be used to prevent catastrophic breakdowns. Deep-learning networks perform automatic feature extraction without human intervention, unlike most traditional machine-learning algorithms. Given that feature extraction is a task that can take teams of data scientists years to accomplish, deep learning is a way to circumvent the chokepoint of limited experts. It augments the powers of small data science teams, which by their nature do not scale. When training on unlabeled data, each node layer in a deep network learns features automatically by repeatedly trying to reconstruct the input from which it draws its samples, attempting to minimize the difference between the networks guesses and the probability distribution of the input data itself. Restricted Boltzmann machines, for examples, create so-called reconstructions in this manner. In the process, these neural networks learn to recognize correlations between certain relevant features and optimal results they draw connections between feature signals and what those features represent, whether it be a full reconstruction, or with labeled data. A deep-learning network trained on labeled data can then be applied to unstructured data, giving it access to much more input than machine-learning nets. This is a recipe for higher performance: the more data a net can train on, the more accurate it is likely to be. (Bad algorithms trained on lots of data can outperform good algorithms trained on very little.) Deep learnings ability to process and learn from huge quantities of unlabeled data give it a distinct advantage over previous algorithms. Deep-learning networks end in an output layer: a logistic, or softmax, classifier that assigns a likelihood to a particular outcome or label. We call that predictive, but it is predictive in a broad sense. Given raw data in the form of an image, a deep-learning network may decide, for example, that the input data is 90 percent likely to represent a person. Example: Feedforward Networks Our goal in using a neural net is to arrive at the point of least error as fast as possible. We are running a race, and the race is around a track, so we pass the same points repeatedly in a loop. The starting line for the race is the state in which our weights are initialized, and the finish line is the state of those parameters when they are capable of producing sufficiently accurate classifications and predictions. The race itself involves many steps, and each of those steps resembles the steps before and after. Just like a runner, we will engage in a repetitive act over and over to arrive at the finish. Each step for a neural network involves a guess, an error measurement and a slight update in its weights, an incremental adjustment to the coefficients, as it slowly learns to pay attention to the most important features. A collection of weights, whether they are in their start or end state, is also called a model, because it is an attempt to model datas relationship to ground-truth labels, to grasp the datas structure. Models normally start out bad and end up less bad, changing over time as the neural network updates its parameters. This is because a neural network is born in ignorance. It does not know which weights and biases will translate the input best to make the correct guesses. It has to start out with a guess, and then try to make better guesses sequentially as it learns from its mistakes. (You can think of a neural network as a miniature enactment of the scientific method, testing hypotheses and trying again only it is the scientific method with a blindfold on. Or like a child: they are born not knowing much, and through exposure to life experience, they slowly learn to solve problems in the world. For neural networks, data is the only experience.) Here is a simple explanation of what happens during learning with a feedforward neural network, the simplest architecture to explain. Input enters the network. The coefficients, or weights, map that input to a set of guesses the network makes at the end. Weighted input results in a guess about what that input is. The neural then takes its guess and compares it to a ground-truth about the data, effectively asking an expert Did I get this right? ground truth - guess = error The difference between the networks guess and the ground truth is its error. The network measures that error, and walks the error back over its model, adjusting weights to the extent that they contributed to the error. error * weight's contribution to error = adjustment The three pseudo-mathematical formulas above account for the three key functions of neural networks: scoring input, calculating loss and applying an update to the model to begin the three-step process over again. A neural network is a corrective feedback loop, rewarding weights that support its correct guesses, and punishing weights that lead it to err. Lets linger on the first step above. Multiple Linear Regression Despite their biologically inspired name, artificial neural networks are nothing more than math and code, like any other machine-learning algorithm. In fact, anyone who understands linear regression, one of first methods you learn in statistics, can understand how a neural net works. In its simplest form, linear regression is expressed as where Y_hat is the estimated output, X is the input, b is the slope and a is the intercept of a line on the vertical axis of a two-dimensional graph. (To make this more concrete: X could be radiation exposure and Y could be the cancer risk; X could be daily pushups and Y_hat could be the total weight you can benchpress; X the amount of fertilizer and Y_hat the size of the crop.) You can imagine that every time you add a unit to X, the dependent variable Y_hat increases proportionally, no matter how far along you are on the X axis. That simple relation between two variables moving up or down together is a starting point. The next step is to imagine multiple linear regression, where you have many input variables producing an output variable. Its typically expressed like this: Y_hat = b_1*X_1 + b_2*X_2 + b_3*X_3 + a (To extend the crop example above, you might add the amount of sunlight and rainfall in a growing season to the fertilizer variable, with all three affecting Y_hat.) Now, that form of multiple linear regression is happening at every node of a neural network. For each node of a single layer, input from each node of the previous layer is recombined with input from every other node. That is, the inputs are mixed in different proportions, according to their coefficients, which are different leading into each node of the subsequent layer. In this way, a net tests which combination of input is significant as it tries to reduce error. Once you sum your node inputs to arrive at Y_hat, its passed through a non-linear function. Heres why: If every node merely performed multiple linear regression, Y_hat would increase linearly and without limit as the Xs increase, but that doesnt suit our purposes. What we are trying to build at each node is a switch (like a neuron) that turns on and off, depending on whether or not it should let the signal of the input pass through to affect the ultimate decisions of the network. When you have a switch, you have a classification problem. Does the inputs signal indicate the node should classify it as enough, or not_enough, on or off? A binary decision can be expressed by 1 and 0, and logistic regression is a non-linear function that squashes input to translate it to a space between 0 and 1. The nonlinear transforms at each node are usually s-shaped functions similar to logistic regression. They go by the names of sigmoid (the Greek word for S), tanh, hard tanh, etc., and they shaping the output of each node. The output of all nodes, each squashed into an s-shaped space between 0 and 1, is then passed as input to the next layer in a feed forward neural network, and so on until the signal reaches the final layer of the net, where decisions are made. Gradient Descent The name for one commonly used optimization function that adjusts weights according to the error they caused is called gradient descent. Gradient is another word for slope, and slope, in its typical form on an x-y graph, represents how two variables relate to each other: rise over run, the change in money over the change in time, etc. In this particular case, the slope we care about describes the relationship between the networks error and a single weight; i.e. that is, how does the error vary as the weight is adjusted. To put a finer point on it, which weight will produce the least error? Which one correctly represents the signals contained in the input data, and translates them to a correct classification? Which one can hear nose in an input image, and know that should be labeled as a face and not a frying pan? As a neural network learns, it slowly adjusts many weights so that they can map signal to meaning correctly. The relationship between network Error and each of those weights is a derivative, dE/dw, that measures the degree to which a slight change in a weight causes a slight change in the error. Each weight is just one factor in a deep network that involves many transforms; the signal of the weight passes through activations and sums over several layers, so we use the chain rule of calculus to march back through the networks activations and outputs and finally arrive at the weight in question, and its relationship to overall error. The chain rule in calculus states that In a feedforward network, the relationship between the nets error and a single weight will look something like this: That is, given two variables, Error and weight, that are mediated by a third variable, activation, through which the weight is passed, you can calculate how a change in weight affects a change in Error by first calculating how a change in activation affects a change in Error, and how a change in weight affects a change in activation. The essence of learning in deep learning is nothing more than that: adjusting a models weights in response to the error it produces, until you cant reduce the error any more. Logistic Regression On a deep neural network of many layers, the final layer has a particular role. When dealing with labeled input, the output layer classifies each example, applying the most likely label. Each node on the output layer represents one label, and that node turns on or off according to the strength of the signal it receives from the previous layers input and parameters. Each output node produces two possible outcomes, the binary output values 0 or 1, because an input variable either deserves a label or it does not. After all, there is no such thing as a little pregnant. While neural networks working with labeled data produce binary output, the input they receive is often continuous. That is, the signals that the network receives as input will span a range of values and include any number of metrics, depending on the problem it seeks to solve. For example, a recommendation engine has to make a binary decision about whether to serve an ad or not. But the input it bases its decision on could include how much a customer has spent on Amazon in the last week, or how often that customer visits the site. So the output layer has to condense signals such as $67.59 spent on diapers, and 15 visits to a website, into a range between 0 and 1; i.e. a probability that a given input should be labeled or not. The mechanism we use to convert continuous signals into binary output is called logistic regression. The name is unfortunate, since logistic regression is used for classification rather than regression in the linear sense that most people are familiar with. It calculates the probability that a set of inputs match the label. Lets examine this little formula. For continuous inputs to be expressed as probabilities, they must output positive results, since there is no such thing as a negative probability. Thats why you see input as the exponent of e in the denominator because exponents force our results to be greater than zero. Now consider the relationship of es exponent to the fraction 1/1. One, as we know, is the ceiling of a probability, beyond which our results cant go without being absurd. (Were 120% sure of that.) As the input x that triggers a label grows, the expression e to the x shrinks toward zero, leaving us with the fraction 1/1, or 100%, which means we approach (without ever quite reaching) absolute certainty that the label applies. Input that correlates negatively with your output will have its value flipped by the negative sign on es exponent, and as that negative signal grows, the quantity e to the x becomes larger, pushing the entire fraction ever closer to zero. Now imagine that, rather than having x as the exponent, you have the sum of the products of all the weights and their corresponding inputs the total signal passing through your net. Thats what youre feeding into the logistic regression layer at the output layer of a neural network classifier. With this layer, we can set a decision threshold above which an example is labeled 1, and below which it is not. You can set different thresholds as you prefer a low threshold will increase the number of false positives, and a higher one will increase the number of false negatives depending on which side you would like to err. Neural Networks & Artificial Intelligence In some circles, neural networks are synonymous with AI. In others, they are thought of as a brute force technique, characterized by a lack of intelligence, because they start with a blank slate, and they hammer their way through to an accurate model. By this interpretation,neural networks are effective, but inefficient in their approach to modeling, since they dont make assumptions about functional dependencies between output and input. For what its worth, the foremost AI research groups are pushing the edge of the discipline by training larger and larger neural networks. Brute force works. It is a necessary, if not sufficient, condition to AI breakthroughs. OpenAIs pursuit of more general AI emphasizes a brute force approach, which has proven effective with well-known models such as GPT-3. Algorithms such as Hintons capsule networks require far fewer instances of data to converge on an accurate model; that is, present research has the potential to resolve the brute force inefficiencies of deep learning. While neural networks are useful as a function approximator, mapping inputs to outputs in many tasks of perception, to achieve a more general intelligence, they can be combined with other AI methods to perform more complex tasks. For example, deep reinforcement learning embeds neural networks within a reinforcement learning framework, where they map actions to rewards in order to achieve goals. Deepminds victories in video games and the board game of go are good examples. Further Reading by Chris Woodford. Last updated: May 12, 2023. Which is bettercomputer or brain? Ask most people if they want a brain like a computer and they'd probably jump at the chance. But look at the kind of work scientists have been doing over the last couple of decades and you'll find many of them have been trying hard to make their computers more like brains! How? With the help of neural networkscomputer programs assembled from hundreds, thousands, or millions of artificial brain cells that learn and behave in a remarkably similar way to human brains. What exactly are neural networks? How do they work? Let's take a closer look! Photo: Computers and brains have much in common, but they're essentially very different. What happens if you combine the best of both worldsthe systematic power of a computer and the densely interconnected cells of a brain? You get a superbly useful neural network. Contents You often hear people comparing the human brain and the electronic computer and, on the face of it, they do have things in common. A typical brain contains something like 100 billion minuscule cells called neurons (no-one knows exactly how many there are and estimates go from about 50 billion to as many as 500 billion).[1] Each neuron is made up of a cell body (the central mass of the cell) with a number of connections coming off it: numerous dendrites (the cell's inputscarrying information toward the cell body) and a single axon (the cell's outputcarrying information away). Neurons are so tiny that you could pack about 100 of their cell bodies into a single millimeter. (It's also worth noting, briefly in passing, that neurons make up only 1050 percent of all the cells in the brain; the rest are glial cells, also called neuroglia, that support and protect the neurons and feed them with energy that allows them to work and grow.) [1] Inside a computer, the equivalent to a brain cell is ananoscopically tiny switching device called a transistor. The latest, cutting-edge microprocessors (single-chip computers) contain over 50 billion transistors; even a basic Pentium microprocessorfrom about 20 years ago had about 50 million transistors, all packed onto an integrated circuit just 25mm square (smaller than a postage stamp)! [2] Artwork: A neuron: the basic structure of a brain cell, showing the central cell body, the dendrites (leading into the cell body), and the axon (leading away from it). That's where the comparison between computers and brains begins and ends, because the two things are completely different. It's not just that computers are cold metal boxes stuffed full of binary numbers, while brains are warm, living, things packed with thoughts, feelings, and memories. The real difference is that computers and brains "think" in completely different ways. The transistors in a computer are wired in relatively simple, serial chains (each one is connected to maybe two or three others in basic arrangements known as logic gates), whereas the neurons in a brain are densely interconnected in complex, parallel ways (each one is connected to perhaps 10,000 of its neighbors). [3] This essential structural difference between computers (with maybe a few hundred million transistors connected in a relatively simple way) and brains (perhaps 10100 times more brain cells connected in richer and more complex ways) is what makes them "think" so very differently. Computers are perfectly designed for storing vast amounts of meaningless (to them) information and rearranging it in any number of ways according to precise instructions (programs) we feed into them in advance. Brains, on the other hand, learn slowly, by a more roundabout method, often taking months or years to make complete sense of something really complex. But, unlike computers, they can spontaneously put information together in astounding new waysthat's where the human creativity of a Beethoven or a Shakespeare comes fromrecognizing original patterns, forging connections, and seeing the things they've learned in a completely different light. Wouldn't it be great if computers were more like brains? That's where neural networks come in!Photo: Electronic brain? Not quite. Computer chips are made from thousands, millions, and sometimes even billions of tiny electronic switches called transistors. That sounds like a lot, but there are still far fewer of them than there are cells in the human brain. What is a neural network? The basic idea behind a neural network is to simulate (copy in a simplified but reasonably faithful way) lots of densely interconnected brain cells inside a computer so you can get it to learn things, recognize patterns, and make decisions in a humanlike way. The amazing thing about a neural network is that you don't have to program it to learn explicitly: it learns all by itself, just like a brain! But it isn't a brain. It's important to note that neural networks are (generally) software simulations: they're made by programming very ordinary computers, working in a very traditional fashion with their ordinary transistors and serially connected logic gates, to behave as though they're built from billions of highly interconnected brain cells working in parallel. No-one has yet attempted to build a computer by wiring up transistors in a densely parallel structure exactly like the human brain. In other words, a neural network differs from a human brain in exactly the same way that a computer model of the weather differs from real clouds, snowflakes, or sunshine. Computer simulations are just collections of algebraic variables and mathematical equations linking them together (in other words, numbers stored in boxes whose values are constantly changing). They mean nothing whatsoever to the computers they run insideonly to the people who program them. Real and artificial neural networksBefore we go any further, it's also worth noting some jargon. Strictly speaking, neural networks produced this way are called artificial neural networks (or ANNs) to differentiate them from the real neural networks (collections of interconnected brain cells) we find inside our brains. You might also see neural networks referred to by names like connectionist machines (the field is also called connectionism), parallel distributed processors (PDP), thinking machines, and so onbut in this article we're going to use the term "neural network" throughout and always use it to mean "artificial neural network." What does a neural network consist of? A typical neural network has anything from a few dozen to hundreds, thousands, or even millions of artificial neurons calledunits arranged in a series of layers, each of which connects to the layers on either side. Some of them, known as input units, are designed to receive various forms of information from the outside world that the network will attempt to learn about, recognize, or otherwise process. Other units sit on the opposite side of the network and signal how it responds to the information it's learned; those are known as output units. In between the input units and output units are one or more layers of hidden units, which, together, form the majority of the artificial brain. Most neural networks are fully connected, which means each hidden unit and each output unit is connected to every unit in the layers either side. The connections between one unit and another are represented by a number called a weight, which can be either positive (if one unit excites another) or negative (if one unit suppresses or inhibits another). The higher the weight, the more influence one unit has on another. (This corresponds to the way actual brain cells trigger one another across tiny gaps called synapses.) Photo: A fully connected neural network is made up of input units (red), hidden units (blue), and output units (yellow), with all the units connected to all the units in the layers either side. Inputs are fed in from the left, activate the hidden units in the middle, and make outputs feed out from the right. The strength (weight) of the connection between any two units is gradually adjusted as the network learns. Deep neural networks Although a simple neural network for simple problem solving could consist of just three layers, as illustrated here, it could also consist of many different layers between the input and the output. A richer structure like this is called a deep neural network (DNN), and it's typically used for tackling much more complex problems. In theory, a DNN can map any kind of input to any kind of output, but the drawback is that it needs considerably more training: it needs to "see" millions or billions of examples compared to perhaps the hundreds or thousands that a simpler network might need. Deep or "shallow," however it's structured and however we choose to illustrate it on the page, it's worth reminding ourselves, once again, that a neural network is not actually a brain or anything brain like. Ultimately, it's a bunch of clever math... a load of equations... an algorithm, if you prefer. [4] Other types of neural networks Most neural networks are designed upfront to solve a particular problem. So they're designed, built, and trained on masses of data, and then they spend the rest of their days processingsimilar data, and churning out solutions to essentially the same problem, over and over again. But human brains don't really work that way: we're much more adaptable to the ever-changing world around us. Liquid neural networks (LNN) are ones that replicate this adaptibility, to an extent, by modifying their algorithms and equations to suit their environments. How does a neural network learn things? Information flows through a neural network in two ways. When it's learning (being trained) or operating normally (after being trained), patterns of information are fed into the network via the input units, which trigger the layers of hidden units, and these in turn arrive at the output units. This common design is called a feedforward network. Not all units "fire" all the time. Each unit receives inputs from the units to its left, and the inputs are multiplied by the weights of the connections they travel along. Every unit adds up all the inputs it receives in this way and (in the simplest type of network) if the sum is more than a certain threshold value, the unit "fires" and triggers the units it's connected to (those on its right). Photo: Bowling: You learn how to do skillful things like this with the help of the neural network inside your brain. Every time you throw the ball wrong, you learn what corrections you need to make next time. Photo by Kenneth R. Hendrix/US Navypublished on Flickr. For a neural network to learn, there has to be an element of feedback involvedjust as children learn by being told what they're doing right or wrong. In fact, we all use feedback, all the time. Think back to when you first learned to play a game like ten-pin bowling. As you picked up the heavy ball and rolled it down the alley, your brain watched how quickly the ball moved and the line it followed, and noted how close you came to knocking down the skittles. Next time it was your turn, you remembered what you'd done wrong before, modified your movements accordingly, and hopefully threw the ball a bit better. So you used feedback to compare the outcome you wanted with what actually happened, figured out the difference between the two, and used that to change what you did next time ("I need to throw it harder," "I need to roll slightly more to the left," "I need to let go later," and so on). The bigger the difference between the intended and actual outcome, the more radically you would have altered your moves. Neural networks learn things in exactly the same way, typically by a feedback process called backpropagation (sometimes abbreviated as "backprop"). This involves comparing the output a network produces with the output it was meant to produce, and using the difference between them to modify the weights of the connections between the units in the network, working from the output units through the hidden units to the input unitsgoing backward, in other words. In time, backpropagation causes the network to learn, reducing the difference between actual and intended output to the point where the two exactly coincide, so the network figures things out exactly as it should. Artwork: A neural network can learn by backpropagation, which is a kind of feedback process that passes corrective values backward through the network. Simple neural networks use simple math: they use basic multiplication to weight the connections between different units. Some neural networks learn to recognize patterns in data using more complex and elaborate math. Known as convolutional neural networks (CNNs or, sometimes, "ConvNets") their input layers take in 2D or 3D "tables" of data (like the matrices you might remember learning about in school). Their hidden layers (sometimes several dozen of them) include some that perform a mathematical process called convolution. Simply speaking, convolutional layers recognize significant patterns hidden in data and "concentrate" them into an easier-to-use form. Essentially, they're detecting key features, which can then be classified by further layers that work like a more traditional neural network. CNNs are particularly good at classifying images or videos, recognizing handwriting, and so on. Artwork: This convolutional neural network (greatly simplified) extracts and emphasizes key features (by the mathematical process of convolutionbroadly a kind of matrix multiplication). These are fed into a more conventional neural network, which uses them to recognize an unknown object or image. How does it work in practice? Once the network has been trained with enough learning examples, it reaches a point where you can present it with an entirely new set of inputs it's never seen before and see how it responds. For example, suppose you've been teaching a network by showing it lots of pictures of chairs and tables, represented in some appropriate way it can understand, and telling it whether each one is a chair or a table. After showing it, let's say, 25 different chairs and 25 different tables, you feed it a picture of some new design it's not encountered beforelet's say a chaise longueand see what happens. Depending on how you've trained it, it'll attempt to categorize the new example as either a chair or a table, generalizing on the basis of its past experiencejust like a human. Hey presto, you've taught a computer how to recognize furniture! That doesn't mean to say a neural network can just "look" at pieces of furniture and instantly respond to them in meaningful ways; it's not behaving like a person. Consider the example we've just given: the network is not actually looking at pieces of furniture. The inputs to a network are essentially binary numbers: each input unit is either switched on or switched off. So if you had five input units, you could feed in information about five different characteristics of different chairs using binary (yes/no) answers. The questions might be 1) Does it have a back? 2) Does it have a top? 3) Does it have soft upholstery? 4) Can you sit on it comfortably for long periods of time? 5) Can you put lots of things on top of it? A typical chair would then present as Yes, No, Yes, Yes, No or 10110 in binary, while a typical table might be No, Yes, No, No, Yes or 01001. So, during the learning phase, the network is simply looking at lots of numbers like 10110 and 01001 and learning that some mean chair (which might be an output of 1) while others mean table (an output of 0). What are neural networks used for? Photo: For the last two decades, NASA has been experimenting with a self-learning neural network calledIntelligent Flight Control System (IFCS) that can help pilots land planes after suffering major failures or damage in battle. The prototype was tested on this modified NF-15B plane (a relative of the McDonnell Douglas F-15). Photo by Jim Ross courtesy of NASA. On the basis of this example, you can probably see lots of different applications for neural networks that involve recognizing patterns and making simple decisions about them. In airplanes, you might use a neural network as a basic autopilot, with input units reading signals from the various cockpit instruments and output units modifying the plane's controls appropriately to keep it safely on course. Inside a factory, you could use a neural network for quality control. Let's say you're producing clothes washing detergent in some giant, convoluted chemical process. You could measure the final detergent in various ways (its color, acidity, thickness, or whatever), feed those measurements into your neural network as inputs, and then have the network decide whether to accept or reject the batch. There are lots of applications for neural networks in security, too. Suppose you're running a bank with many thousands of credit-card transactions passing through your computer system every single minute. You need a quick automated way of identifying any transactions that might be fraudulentand that's something for which a neural network is perfectly suited. Your inputs would be things like 1) Is the cardholder actually present? 2) Has a valid PIN number been used? 3) Have five or more transactions been presented with this card in the last 10 minutes? 4) Is the card being used in a different country from which it's registered? and so on. With enough clues, a neural network can flag up any transactions that look suspicious, allowing a human operator to investigate them more closely. In a very similar way, a bank could use a neural network to help it decide whether to give loans to people on the basis of their past credit history, current earnings, and employment record. Photo: Handwriting recognition on a touchscreen, tablet computer is one of many applications perfectly suited to a neural network. Each character (letter, number, or symbol) that you write is recognized on the basis of key features it contains (vertical lines, horizontal lines, angled lines, curves, and so on) and the order in which you draw them on the screen. Neural networks get better and better at recognizing over time. Many of the things we all do everyday involve recognizing patterns and using them to make decisions, so neural networks can help us out in zillions of different ways. They can help us forecast the stockmarket or the weather, operate radar scanning systems that automatically identify enemy aircraft or ships, and even help doctors to diagnose complex diseases on the basis of their symptoms. There might be neural networks ticking away inside your computer or your cellphone right this minute. If you use cellphone apps that recognize your handwriting on a touchscreen, they might be using a simple neural network to figure out which characters you're writing by looking out for distinct features in the marks you make with your fingers (and the order in which you make them). Some kinds of voice recognition software also use neural networks. And so do some of the email programs that automatically differentiate between genuine emails and spam.Neural networks have even proved effective in translating text from one language to another. Google's automatic translation, for example, has made increasing use of this technology over the last few years to convert words in one language (the network's input) into the equivalent words in another language (the network's output). In 2016, Google announced it was using something it called Neural Machine Translation (NMT) to convert entire sentences, instantly, with a5585 percent reduction in errors. This is just one example of how Google deploys neural-network technology: Google Brainis the name it's given to a massive research effort that applies neural techniques across its whole range of products, including its search engine. It also uses deep neural networks to power the recommendations you see on YouTube, with models that "learn approximatelyone billion parameters and are trained on hundreds of billions of examples." [5] All in all, neural networks have made computer systems more useful by making them more human. So next time you think you might like your brain to be as reliable as a computer, think againand be grateful you have such a superb neural network already installed in your head! Chris Woodford is the author and editor of dozens of science and technology books for adults and children, including DK's worldwide bestselling Cool Stuff series and Atoms Under the Floorboards, which won the American Institute of Physics Science Writing award in 2016. You can hire him to write books, articles, scripts, corporate copy, and more via his website chriswoodford.com. by Chris Woodford. Last updated: May 12, 2023. Which is bettercomputer or brain? Ask most people if they want a brain like a computer and they'd probably jump at the chance. But look at the kind of work scientists have been doing over the last couple of decades and you'll find many of them have been trying hard to make their computers more like brains! How? With the help of neural networkscomputer programs assembled from hundreds, thousands, or millions of artificial brain cells that learn and behave in a remarkably similar way to human brains. What exactly are neural networks? How do they work? Let's take a closer look! Photo: Computers and brains have much in common, but they're essentially very different. What happens if you combine the best of both worldsthe systematic power of a computer and the densely interconnected cells of a brain? You get a superbly useful neural network. Contents You often hear people comparing the human brain and the electronic computer and, on the face of it, they do have things in common. A typical brain contains something like 100 billion minuscule cells called neurons (no-one knows exactly how many there are and estimates go from about 50 billion to as many as 500 billion).[1] Each neuron is made up of a cell body (the central mass of the cell) with a number of connections coming off it: numerous dendrites (the cell's inputscarrying information toward the cell body) and a single axon (the cell's outputcarrying information away). Neurons are so tiny that you could pack about 100 of their cell bodies into a single millimeter. (It's also worth noting, briefly in passing, that neurons make up only 1050 percent of all the cells in the brain; the rest are glial cells, also called neuroglia, that support and protect the neurons and feed them with energy that allows them to work and grow.) [1] Inside a computer, the equivalent to a brain cell is ananoscopically tiny switching device called a transistor. The latest, cutting-edge microprocessors (single-chip computers) contain over 50 billion transistors; even a basic Pentium microprocessorfrom about 20 years ago had about 50 million transistors, all packed onto an integrated circuit just 25mm square (smaller than a postage stamp)! [2] Artwork: A neuron: the basic structure of a brain cell, showing the central cell body, the dendrites (leading into the cell body), and the axon (leading away from it). That's where the comparison between computers and brains begins and ends, because the two things are completely different. It's not just that computers are cold metal boxes stuffed full of binary numbers, while brains are warm, living, things packed with thoughts, feelings, and memories. The real difference is that computers and brains "think" in completely different ways. The transistors in a computer are wired in relatively simple, serial chains (each one is connected to maybe two or three others in basic arrangements known as logic gates), whereas the neurons in a brain are densely interconnected in complex, parallel ways (each one is connected to perhaps 10,000 of its neighbors). [3] This essential structural difference between computers (with maybe a few hundred million transistors connected in a relatively simple way) and brains (perhaps 10100 times more brain cells connected in richer and more complex ways) is what makes them "think" so very differently. Computers are perfectly designed for storing vast amounts of meaningless (to them) information and rearranging it in any number of ways according to precise instructions (programs) we feed into them in advance. Brains, on the other hand, learn slowly, by a more roundabout method, often taking months or years to make complete sense of something really complex. But, unlike computers, they can spontaneously put information together in astounding new waysthat's where the human creativity of a Beethoven or a Shakespeare comes fromrecognizing original patterns, forging connections, and seeing the things they've learned in a completely different light. Wouldn't it be great if computers were more like brains? That's where neural networks come in!Photo: Electronic brain? Not quite. Computer chips are made from thousands, millions, and sometimes even billions of tiny electronic switches called transistors. That sounds like a lot, but there are still far fewer of them than there are cells in the human brain. What is a neural network? The basic idea behind a neural network is to simulate (copy in a simplified but reasonably faithful way) lots of densely interconnected brain cells inside a computer so you can get it to learn things, recognize patterns, and make decisions in a humanlike way. The amazing thing about a neural network is that you don't have to program it to learn explicitly: it learns all by itself, just like a brain! But it isn't a brain. It's important to note that neural networks are (generally) software simulations: they're made by programming very ordinary computers, working in a very traditional fashion with their ordinary transistors and serially connected logic gates, to behave as though they're built from billions of highly interconnected brain cells working in parallel. No-one has yet attempted to build a computer by wiring up transistors in a densely parallel structure exactly like the human brain. In other words, a neural network differs from a human brain in exactly the same way that a computer model of the weather differs from real clouds, snowflakes, or sunshine. Computer simulations are just collections of algebraic variables and mathematical equations linking them together (in other words, numbers stored in boxes whose values are constantly changing). They mean nothing whatsoever to the computers they run insideonly to the people who program them. Real and artificial neural networksBefore we go any further, it's also worth noting some jargon. Strictly speaking, neural networks produced this way are called artificial neural networks (or ANNs) to differentiate them from the real neural networks (collections of interconnected brain cells) we find inside our brains. You might also see neural networks referred to by names like connectionist machines (the field is also called connectionism), parallel distributed processors (PDP), thinking machines, and so onbut in this article we're going to use the term "neural network" throughout and always use it to mean "artificial neural network." What does a neural network consist of? A typical neural network has anything from a few dozen to hundreds, thousands, or even millions of artificial neurons calledunits arranged in a series of layers, each of which connects to the layers on either side. Some of them, known as input units, are designed to receive various forms of information from the outside world that the network will attempt to learn about, recognize, or otherwise process. Other units sit on the opposite side of the network and signal how it responds to the information it's learned; those are known as output units. In between the input units and output units are one or more layers of hidden units, which, together, form the majority of the artificial brain. Most neural networks are fully connected, which means each hidden unit and each output unit is connected to every unit in the layers either side. The connections between one unit and another are represented by a number called a weight, which can be either positive (if one unit excites another) or negative (if one unit suppresses or inhibits another). The higher the weight, the more influence one unit has on another. (This corresponds to the way actual brain cells trigger one another across tiny gaps called synapses.) Photo: A fully connected neural network is made up of input units (red), hidden units (blue), and output units (yellow), with all the units connected to all the units in the layers either side. Inputs are fed in from the left, activate the hidden units in the middle, and make outputs feed out from the right. The strength (weight) of the connection between any two units is gradually adjusted as the network learns. Deep neural networks Although a simple neural network for simple problem solving could consist of just three layers, as illustrated here, it could also consist of many different layers between the input and the output. A richer structure like this is called a deep neural network (DNN), and it's typically used for tackling much more complex problems. In theory, a DNN can map any kind of input to any kind of output, but the drawback is that it needs considerably more training: it needs to "see" millions or billions of examples compared to perhaps the hundreds or thousands that a simpler network might need. Deep or "shallow," however it's structured and however we choose to illustrate it on the page, it's worth reminding ourselves, once again, that a neural network is not actually a brain or anything brain like. Ultimately, it's a bunch of clever math... a load of equations... an algorithm, if you prefer. [4] Other types of neural networks Most neural networks are designed upfront to solve a particular problem. So they're designed, built, and trained on masses of data, and then they spend the rest of their days processingsimilar data, and churning out solutions to essentially the same problem, over and over again. But human brains don't really work that way: we're much more adaptable to the ever-changing world around us. Liquid neural networks (LNN) are ones that replicate this adaptibility, to an extent, by modifying their algorithms and

equations to suit their environments. How does a neural network learn things? Information flows through a neural network in two ways. When it's learning (being trained) or operating normally (after being trained), patterns of information are fed into the network via the input units, which trigger the layers of hidden units, and these in turn arrive at the output units. This common design is called a feedforward network. Not all units "fire" all the time. Each unit receives inputs from the units to its left, and the inputs are multiplied by the weights of the connections they travel along. Every unit adds up all the inputs it receives in this way and (in the simplest type of network) if the sum is more than a certain threshold value, the unit "fires" and triggers the units it's connected to (those on its right). Photo: Bowling: You learn how to do skillful things like this with the help of the neural network inside your brain. Every time you throw the ball wrong, you learn what corrections you need to make next time. Photo by Kenneth R. Hendrix/US Navypublished on Flickr. For a neural network to learn, there has to be an element of feedback involvedjust as children learn by being told what they're doing right or wrong. In fact, we all use feedback, all the time. Think back to when you first learned to play a game like ten-pin bowling. As you picked up the heavy ball and rolled it down the alley, your brain watched how quickly the ball moved and the line it followed, and noted how close you came to knocking down the skittles. Next time it was your turn, you remembered what you'd done wrong before, modified your movements accordingly, and hopefully threw the ball a bit better. So you used feedback to compare the outcome you wanted with what actually happened, figured out the difference between the two, and used that to change what you did next time ("I need to throw it harder," "I need to roll slightly more to the left," "I need to let go later," and so on). The bigger the difference between the intended and actual outcome, the more radically you would have altered your moves. Neural networks learn things in exactly the same way, typically by a feedback process called backpropagation (sometimes abbreviated as "backprop"). This involves comparing the output a network produces with the output it was meant to produce, and using the difference between them to modify the weights of the connections between the units in the network, working from the output units through the hidden units to the input unitsgoing backward, in other words. In time, backpropagation causes the network to learn, reducing the difference between actual and intended output to the point where the two exactly coincide, so the network figures things out exactly as it should. Artwork: A neural network can learn by backpropagation, which is a kind of feedback process that passes corrective values backward through the network. Simple neural networks use simple math: they use basic multiplication to weight the connections between different units. Some neural networks learn to recognize patterns in data using more complex and elaborate math. Known as convolutional neural networks (CNNs or, sometimes, "ConvNets") their input layers take in 2D or 3D "tables" of data (like the matrices you might remember learning about in school). Their hidden layers (sometimes several dozen of them) include some that perform a mathematical process called convolution. Simply speaking, convolutional layers recognize significant patterns hidden in data and "concentrate" them into an easier-to-use form. Essentially, they're detecting key features, which can then be classified by further layers that work like a more traditional neural network. CNNs are particularly good at classifying images or videos, recognizing handwriting, and so on. Artwork: This convolutional neural network (greatly simplified) extracts and emphasizes key features (by the mathematical process of convolutionbroadly a kind of matrix multiplication). These are fed into a more conventional neural network, which uses them to recognize an unknown object or image. How does it work in practice? Once the network has been trained with enough learning examples, it reaches a point where you can present it with an entirely new set of inputs it's never seen before and see how it responds. For example, suppose you've been teaching a network by showing it lots of pictures of chairs and tables, represented in some appropriate way it can understand, and telling it whether each one is a chair or a table. After showing it, let's say, 25 different chairs and 25 different tables, you feed it a picture of some new design it's not encountered beforelet's say a chaise longueand see what happens. Depending on how you've trained it, it'll attempt to categorize the new example as either a chair or a table, generalizing on the basis of its past experiencejust like a human. Hey presto, you've taught a computer how to recognize furniture! That doesn't mean to say a neural network can just "look" at pieces of furniture and instantly respond to them in meaningful ways; it's not behaving like a person. Consider the example we've just given: the network is not actually looking at pieces of furniture. The inputs to a network are essentially binary numbers: each input unit is either switched on or switched off. So if you had five input units, you could feed in information about five different characteristics of different chairs using binary (yes/no) answers. The questions might be 1) Does it have a back? 2) Does it have a top? 3) Does it have soft upholstery? 4) Can you sit on it comfortably for long periods of time? 5) Can you put lots of things on top of it? A typical chair would then present as Yes, No, Yes, Yes, No or 10110 in binary, while a typical table might be No, Yes, No, No, Yes or 01001. So, during the learning phase, the network is simply looking at lots of numbers like 10110 and 01001 and learning that some mean chair (which might be an output of 1) while others mean table (an output of 0). What are neural networks used for? Photo: For the last two decades, NASA has been experimenting with a self-learning neural network calledIntelligent Flight Control System (IFCS) that can help pilots land planes after suffering major failures or damage in battle. The prototype was tested on this modified NF-15B plane (a relative of the McDonnell Douglas F-15). Photo by Jim Ross courtesy of NASA. On the basis of this example, you can probably see lots of different applications for neural networks that involve recognizing patterns and making simple decisions about them. In airplanes, you might use a neural network as a basic autopilot, with input units reading signals from the various cockpit instruments and output units modifying the plane's controls appropriately to keep it safely on course. Inside a factory, you could use a neural network for quality control. Let's say you're producing clothes washing detergent in some giant, convoluted chemical process. You could measure the final detergent in various ways (its color, acidity, thickness, or whatever), feed those measurements into your neural network as inputs, and then have the network decide whether to accept or reject the batch. There are lots of applications for neural networks in security, too. Suppose you're running a bank with many thousands of credit-card transactions passing through your computer system every single minute. You need a quick automated way of identifying any transactions that might be fraudulentand that's something for which a neural network is perfectly suited. Your inputs would be things like 1) Is the cardholder actually present? 2) Has a valid PIN number been used? 3) Have five or more transactions been presented with this card in the last 10 minutes? 4) Is the card being used in a different country from which it's registered? and so on. With enough clues, a neural network can flag up any transactions that look suspicious, allowing a human operator to investigate them more closely. In a very similar way, a bank could use a neural network to help it decide whether to give loans to people on the basis of their past credit history, current earnings, and employment record. Photo: Handwriting recognition on a touchscreen, tablet computer is one of many applications perfectly suited to a neural network. Each character (letter, number, or symbol) that you write is recognized on the basis of key features it contains (vertical lines, horizontal lines, angled lines, curves, and so on) and the order in which you draw them on the screen. Neural networks get better and better at recognizing over time. Many of the things we all do everyday involve recognizing patterns and using them to make decisions, so neural networks can help us out in zillions of different ways. They can help us forecast the stockmarket or the weather, operate radar scanning systems that automatically identify enemy aircraft or ships, and even help doctors to diagnose complex diseases on the basis of their symptoms. There might be neural networks ticking away inside your computer or your cellphone right this minute. If you use cellphone apps that recognize your handwriting on a touchscreen, they might be using a simple neural network to figure out which characters you're writing by looking out for distinct features in the marks you make with your fingers (and the order in which you make them). Some kinds of voice recognition software also use neural networks. And so do some of the email programs that automatically differentiate between genuine emails and spam.Neural networks have even proved effective in translating text from one language to another. Google's automatic translation, for example, has made increasing use of this technology over the last few years to convert words in one language (the network's input) into the equivalent words in another language (the network's output). In 2016, Google announced it was using something it called Neural Machine Translation (NMT) to convert entire sentences, instantly, with a5585 percent reduction in errors. This is just one example of how Google deploys neural-network technology: Google Brainis the name it's given to a massive research effort that applies neural techniques across its whole range of products, including its search engine. It also uses deep neural networks to power the recommendations you see on YouTube, with models that "learn approximatelyone billion parameters and are trained on hundreds of billions of examples." [5] All in all, neural networks have made computer systems more useful by making them more human. So next time you think you might like your brain to be as reliable as a computer, think againand be grateful you have such a superb neural network already installed in your head! Chris Woodford is the author and editor of dozens of science and technology books for adults and children, including DK's worldwide bestselling Cool Stuff series and Atoms Under the Floorboards, which won the American Institute of Physics Science Writing award in 2016. You can hire him to write books, articles, scripts, corporate copy, and more via his website chriswoodford.com.Just imagine what must go on inside the human brain when tasked with recognizing digits, given the varying ways the digits 0-9 can be hand-drawn. Human readers can instantly classify these digits, even from an early age. The goal of neural networks is for a computer algorithm to be able to classify these digits as well as a human. TheMNIST(ModifiedNational Institute of Standards and Technology)database is a largedatasetof handwritten digits that is frequently used fortrainingvariousimage processingand machine learning systems. This video presentation by Michael Garris, senior scientist, provides an overview. You may download the MNIST dataset files directly for further exploration. In this section, we introduce simple models of neural networks and discover how they work. Many technical details are deferred to later sections or are outside the scope of this text. A neural network is a structure made up of components called neurons, which are individual decision-making units that take some number of inputs x1,x2,,xnx1,x2,,xn and produce an output yy, as in Figure 7.2. How the output is determined by the inputs could be quite complex. Moreover, any two neurons may behave quite differently from each other on the same inputs. Figure 7.2 Single Neuron in a Neural Network The neural network itself may consist of hundreds, thousands, or even millions of neurons connected to each other in layers, or groups of neurons that all receive the same inputs from previous layers and forward signals in aggregate to the next layer. There are always at least two layers, the input layer (containing neurons that accept the initial input data) and output layer (containing the neurons that are used to interpret the answer or give classification information), together with some number of hidden layers (layers between the input and output layers). Figure 7.3 shows a simple neural network diagram for reference. Figure 7.3 Neural Network Diagram. This neural network has four layers, two of which are hidden layers. There are three input neurons and one output neuron. In this example, all nodes in adjacent layers are connected, but some neural network models may not include all such connections (see, for example, convolutional neural networks in Introduction to Deep Learning). The main purpose of a neural network is to classify complex data. Problems for which neural networks are especially well suited include the following: Image recognition, including facial recognition, identifying handwritten letters and symbols, and classifying parts of images. This is a huge area of innovation, with powerful tools such as TensorFlow developed by Google and PyTorch developed by Meta. Speech recognition, such as Googles Cloud Speech-to-Text service, offers accurate transcription of speech and translation for various languages. Recommendation systems, which are used to serve ads online based on each users browsing habits, have been developed and used by Amazon, Meta, Netflix, and many other large companies to reach target markets. Anomaly detection has been developed to aid in fraud detection, data security, and error analysis/correction by finding outliers in large, complex datasets. An example is Microsofts Azure Anomaly Detector, which can detect anomalies in time series data. Autonomous vehicles and robotics, including Teslas Autopilot technology, are becoming more and more prominent as automation alleviates some of the routine aspects of daily life and leads to increased efficiencies in business, manufacturing, and transportation. Generative art, examples of which include visual art, music, video, and poetry, leverage vast stores of human creative output to produce novel variations. Predictive text, including natural language processing models such as ChatGPT (see Convolutional Neural Networks). If you want to get your feet wet with neural networks, check out this interactive web-based neural network tool, called TensorFlow Playground, which uses TensorFlow to train and update outputs in real time. There, you can choose a dataset from a list, adjust the number of hidden layers and neurons per layer by clicking the plus (+) and minus (--) buttons, and adjust the learning rate, choice of activation function, and other parameters (topics that we will learn more about in the rest of the chapter). Then click the play button to start training the model and watch as it learns how to classify the points in your chosen dataset! If you want to start over, just click reset and start from scratch! The way neurons work in a neural network is conjectured to be similar, or analogous, to how neurons work in the brain. The input of the neural network is fed into the neurons of the input layer. Each neuron then processes it and produces an output, which is in turn pushed to the neurons in the next layer. Individual neurons only send signals, or activate, if they receive the appropriate input required to activate. (Activation is the process of sending an output signal after having received appropriate input signals.) After passing through some number of hidden layers, the output of the last hidden layer feeds into the output layer. Lastly, the output of this final layer is interpreted based on the nature of the problem. If there is a single output neuron, then the interpretation could be true if that neuron is activated or false if not. For neural networks used to classify input into various classes (e.g., number recognition), there is usually one output neuron per class. The one that is most activated would indicate the classification, as shown in Figure 7.4. Figure 7.4 Output Neurons. In this figure, there are four output neurons, labeled A, B, C, and D. Since B has the highest activation level, the output of the neural network is B. Each connection from one neuron to another has two parameters associated with it. The weight is a value ww that is multiplied to the incoming signal, essentially determining the strength of the connection. The bias is a value bb that is added to the weighted signal, making the neuron more likely (or less likely, if bb is negative) to activate on any given input. The values of ww and bb may be positive, negative, or zero. Once the weight and bias are applied, the result is run through an activation function, which is a non-decreasing function ff that determines whether the neuron activates and, if so, how strongly. (Youll see this later in Figure 7.6.) Consider the simplest case of all, a neuron with single input xx and output yy. Then the flow of signal through the neuron follows the formula y=f(wx+b)y=f(wx+b). For example, suppose that the input value is x=0.87x=0.87, with weight w=0.53w=0.53 and bias b=0.12b=0.12. Then the signal would first be combined as wx+b=(0.53)(0.87)+(0.12)=0.3411wx+b=(0.53)(0.87)+(0.12)=0.3411. This value would be fed as input to the activation function to produce y=f(0.3411)y=f(0.3411). In the next section, we will discuss various activation functions used in neural networks. When there are multiple inputs, x1,x2,,xnx1,x2,,xn, each will be affected by its own weight. Typically, bias is thought of as a property of the neuron itself and so bias affects all the inputs in the same way. To be more precise, first, the inputs are multiplied by their individual weights, the result is summed, and then the bias is added. Finally, the activation function is applied to obtain the output signal. y=f(w1x1+w2x2++wnxn+b)=f((i=1nwixi)+b)y=f(w1x1+w2x2++wnxn+b)=f((i=1nwixi)+b) The weights and biases are parameters that the neural network learns during the training process, a topic we will explain in Backpropagation. A typical neural network may have hundreds or thousands of inputs for each neuron, and so the equation can be difficult to work with. It would be more convenient to regard all the inputs x1,x2,,xnx1,x2,,xn as parts of a single mathematical structure, called a vector. A vector is simply an ordered list of numbers, that is, x=(x1,x2,,xn)x=(x1,x2,,xn). (Note: In this text we use boldface letters to represent vectors. Also, the components of a vector are listed within a set of parentheses. Some texts vary on these notational details.) The number of components in a vector is called its dimension, so for example the vector (5,0,2,1.2,)(5,0,2,1.2,) has dimension 5. Certain arithmetic operations are defined on vectors. Vectors of the same dimension can be added: If x=(x1,x2,,xn)x=(x1,x2,,xn) and y=(y1,y2,,yn)y=(y1,y2,,yn), then x+y=(x1+y1,x2+y2,,xn+yn)x+y=(x1+y1,x2+y2,,xn+yn). Any real number can be multiplied to a vector: kx=k(x1,x2,,xn)=(kx1,kx2,,kxn)kx=k(x1,x2,,xn)=(kx1,kx2,,kxn). The dot product of two vectors of the same dimension results in a real number (not a vector) and is defined by: xy=(x1,x2,,xn)(y1,y2,,yn)=i=1nxiyi=x1y1+x2y2+x3y3++xnynxy=(x1,x2,,xn)(y1,y2,,yn)=i=1nxiyi=x1y1+x2y2+x3y3++xnyn If the inputs and weights are regarded as vectors, x=(x1,x2,,xn)x=(x1,x2,,xn) and w=(w1,w2,,wn)w=(w1,w2,,wn), respectively, then the formula may be re-expressed more concisely as: y=f(wx+b)y=f(wx+b) For example, if w=(0.3,0.1,0.9)w=(0.3,0.1,0.9), x=(1.2,0.4,0.6)x=(1.2,0.4,0.6), and b=0.1b=0.1, then wx+b=(0.3)(1.2)+(0.1)(0.4)+(0.9)(0.6)+0.1=0.12wx+b=(0.3)(1.2)+(0.1)(0.4)+(0.9)(0.6)+0.1=0.12 So in this example, the output would be y=f(0.12)y=f(0.12), the exact value of which depends on which activation function f(x)f(x) is chosen. Activation functions come in many types. Here are just a few of the most common activation functions. Step function, f(x)={0,ifx