Introduction

 Artificial intelligence (AI) has seen an explosion of interest and development over the last several years as a result of widespread internet use and improved computer hardware. Even before the successes of deep learning, optimism about the future of AI and robotics suggested a future where technology rivals human abilities. Media and popular culture throughout the 20th century has showcased future societies both helped and hindered by these technologies, depicting robots from helpful household servants to nefarious, state or corporate entities built for controlling human activity. Determining whether these fictitious accounts are worthy of concern, however, has been a source of debate since their inception, with many believing that AI can assist in improving the lives of individuals and communities around the world. Optimists view robots and AIs as a means for addressing specific problems, such as caring for the elderly in regions where human labour is insufficient for meeting the needs of its populations. In this case, a specific kind of AI is required, one with an ability to socialize with people in a humanlike way. Moreover, some instances of sociable AIs will require a body to act in a familiar, humanlike manner, and learning as children do through experimentation and interacting with its environment. The idea is that if these robots can learn about the world, the meanings of the words and phrases used by humans will be understood through association. For example, the spoken word of an object, in conjunction with the sight of the object, can be learned to ground the meaning of what humans are referring to. If successful, learning can be built up over time as observed in childhood, where robots may one day be able to fulfill the roles once occupied by people.

 This work specifically investigates social robots to determine whether the capacities required to communicate and develop social skills are indeed feasible. One such skill is an ability to understand human emotion through behavioural cues and in language, acting appropriately given the situation and person(s) at hand. Furthermore, social robots should be able to act with empathy, especially if we are interested in using them for tasks related to eldercare and healthcare. The reason for implementing them in these domains is due to an increasing shortage in human labour to meet the growing demand for care, given recent demographic trends observable worldwide. If we are to address these issues with technological solutions, however, robots must be able to interact with people in an intuitive manner, as they would with any human. After introducing the issues motivating these novel solutions, the first chapter of this work examines the components of human communication to identify the requirements of social robots. Although empathy is a significant component of healthcare, it leverages a more fundamental human ability, that of perspective-taking. To know or sense what another person is thinking and feeling is a crucial component of communication, and as such, social robots will require an ability to understand the behavioural cues of human individuals.

 To better understand what empathy and perspective-taking involves, the second chapter investigates the philosophical background and scientific basis of this ability. Originating from the domain of aesthetics and phenomenology, the term *empathy* is often associated with simulating within oneself the perceived feelings of others, as detected by behavioural cues. To facilitate this, one’s own knowledge of others can be leveraged in cases where simulation is insufficient, suggesting that empathy requires both an appeal to knowledge or theory in addition to acts of internal simulation. Overall, however, these two aspects of empathy are best characterized by a particular interaction unfolding between two or more individuals, where situational context plays an important role in whether an act of empathy is successful or not. Given that individuals are unique beings with specific sociocultural backgrounds, it is to be expected that not all acts of empathy will be successful, and any theory of empathy must account for how and why they succeed or fail. As individuals communicate and interact, their attempts to understand one another are influenced by a number of variables, including their similarities and differences, their relationship, and the setting in which they are in, to name a few.

 The chapter which follows begins with an analysis of the history of AI to highlight the developments in this field since its inception, presenting a story of how current AIs came to be. Included in the evolution of AI agents is one which aims to recreate human development in robots, particularly by learning about its environment through play and experimentation. Rather than providing the robot with specific information about the world, it instead learns through interacting with the world, much like human children. One particular robot named iCub appears to be successful in its ability to learn the names of objects and how to use them; for example, picking up a mug by its handle upon hearing the word. Given the successes of iCub, is this robot a good candidate for future social robots? Unfortunately for its developers, it is not given its inability to understand emotions. Although emotional recognition can be added into its functionality, this approach is insufficient for communication and socialization. The reason is because iCub’s motivational framework lacks the kind of affective regulation observed in people and animals. The robot’s inability to *experience* its own version of emotions means it cannot understand what emotions are and what they mean to the human experiencing them. All the information the robot knows about emotions must be provided to it by humans, rather than being generated through its own body. Without this, any recognition exhibited by iCub is necessarily a simulation of true understanding.

 If iCub is incapable of understanding emotions, then what must be done to overcome this limitation? The chapter which follows introduces a new approach to building robots as developed by Dr. Pentti Haikonen. Prior to examining his architecture for neural networks and cognition, the chapter opens with a brief discussion on living beings and a fundamental principle which explains how life emerges and continues to flourish. Through self-organization or *autopoiesis*, physiological processes which constitute the bodies of organisms keep the individual alive, providing a means for restoring diminishing resources and avoiding harms by detecting changes in the environment. Although the history of AI briefly saw these principles adopted into research and development programs, their implementation of autopoiesis did not sufficiently extend to cognition to give rise to behaviours guided by an agent’s own interests. The architecture created by Dr. Haikonen is modelled on biological functionality, and as such, creates a better analogue of living beings than previous efforts in AI. By creating associative networks of neurons which establish connections between stimuli and their effects on the robot’s body, it is able to learn what a stimulus *means* to it and its continued functioning. The associations established in the robot’s “mind” are thus properly grounded in its body, as the presence of pain and pleasure signals indicate how the stimulus impacts its body. This architecture provides a foundation for empathy as the robot is able to appeal to its own sensations of pain and pleasure to understand the meanings of behavioural cues exhibited by humans. Despite requiring an entirely new approach to building robots, the architecture invented by Dr. Haikonen provides a promising solution to overcoming the limitations of existing robots and AI agents.

 Overall, the reason for this project and its suggestion for a new direction in robotics is to prevent harms falling upon human lives. Our ability to anthropomorphize objects and other natural phenomena introduces potential risks arising from misunderstanding the behaviours of AIs. These risks involve emotional and psychological harms from faulty beliefs and unrequited social connections, as an agent which utters sentimental statements is only simulating the way humans and animals interact with people. Incapable of feeling anything at all about the person it is interacting with, it may still act in a way which resembles human feelings or intentions. Any subsequent projection of capacities or abilities onto robots and AIs may lead to false beliefs which in turn introduce hazards to the lives of individuals and communities, potentially relying on these agents for tasks or competencies which they cannot possess. To prevent these outcomes, a robust understanding of what robots are and what they are capable of is imperative. As various kinds of AIs and robots become increasingly commonplace within our societies, it will become increasingly important that our understanding of them is accurate, despite their appearances or claims made by their creators. Although some robots may appear to act intelligently, in actuality, this is in fact a simulation of the true capacity witnessed in humans and animals. The reason is because the self-organizational processes which give rise to biological bodies and cognition have been developed through evolution to keep the organism alive, a feature which is notably absent in manmade artifacts like social robots. As passive objects reliant on human intervention, robots are a fundamentally distinct type of “agent” despite any behaviours exhibited which suggest otherwise.

Chapter 1 – Social Robots for the Future

 There is widespread discussion on the implementation of social robots but will they truly be a part of societies of the future? This chapter outlines the existing and growing demand to create robots capable of interacting with humans. I will argue their presence in human societies is highly likely; however, to be successful, specific components are imperative for their widespread adoption. Social robots must be able to communicate with people with understanding by interpreting utterances and behavioural cues. A significant aspect of this includes their design and physical form to properly reflect the scope and degree of their capacities.

1.1 – Examining the Demand for Social Robots

Historically, robots have been created for industrial environments for manufacturing. A new domain for robotic solutions has since emerged, redefining the commonly-held assumptions about what a robot is.[[1]](#footnote-2) The word ‘robot’ is derived from *robota*, a Czech term for “forced labour” and originally introduced by playwright Karel Čapek in 1920.[[2]](#footnote-3) The term denotes an artificial agent designed to perform dull and dangerous tasks in lieu of human beings. As such, the term has become associated with preprogrammed machines designed to carry out specific tasks in industrial environments. Given this programming, they are unable to act according to their own volition, and incapable of being invested in the world in ways which humans are. Today, robotics development also includes a branch dedicated to creating automated agents capable of interacting with people in a humanlike manner. To be successful, robots designed for social engagement must be able to use and understand linguistic utterances, as well as be able to detect human emotion to respond appropriately.[[3]](#footnote-4) Because robots are often considered to be automated machines designed to perform repetitive movements regardless of context, a social robot shifts this notion substantially, as it must be able to operate in a nuanced, context-dependent manner. Since social interactions and acts of communication can refer to aspects of the current situation, social robots must be able to follow along and respond appropriately. This idea will be discussed in further detail later in this chapter.

 The development of this new branch of robotics began in Japan in the early 2000’s in response to the nation’s demographic crisis. Japanese birthrates have been below replacement levels since 1980[[4]](#footnote-5) and due to increased life expectancy, the elderly population has increased rapidly over the last fifty years.[[5]](#footnote-6) As a result, there has been an increase in demand for governmental services like pensions, medical treatment, and long-term care, while fewer working-age adults are able to care for family members and contribute to the economy to support these government programs.[[6]](#footnote-7) Today, Japan is the world’s most aged country, as it has the lowest mortality rate in the world while also observing low fertility rates.[[7]](#footnote-8) There are many needing care while there are fewer working age adults to support them. With a long history developing industrial robotics, as well as pioneering research into developing humanoid robots, Japan was well-suited to approaching its demographic crisis with robotic solutions.[[8]](#footnote-9) To meet growing demands for elderly care, Japanese researchers began to investigate different ways to support its aging population,[[9]](#footnote-10) leading to promising developments[[10]](#footnote-11) and subsequently becoming an industry leader in this domain.[[11]](#footnote-12) Robots have been designed to assist individuals with sitting, standing, and moving around, in addition to providing support for healthcare workers with lifting and carrying patients.[[12]](#footnote-13) For social support, Japanese researchers began experimenting with a soft companion robot named Paro in 2003 to determine whether it may assist in improving moods and social engagement in elderly individuals.[[13]](#footnote-14) Indeed, this pet-like robot which resembles a baby harp seal has demonstrated positive results in improving emotional, cognitive, and social functioning within nursing home residents.[[14]](#footnote-15) Further research using different types of companion robots has indicated similar results,[[15]](#footnote-16) suggesting overall, these new robotic applications may deliver positive outcomes to elderly individuals. As such, technological solutions for meeting the rising demand of personal care indicates a promising direction for the future.

 Similar demographic crises can be identified worldwide as well. Western countries like the United Kingdom, the United States, Canada, Australia, Germany, and Italy,[[16]](#footnote-17) to name a few, have witnessed an increase in this trend since the 1960’s.[[17]](#footnote-18) Since then, several other countries and regions have followed suit, including China[[18]](#footnote-19), India[[19]](#footnote-20), Iran[[20]](#footnote-21), and several Eastern European ones such as Belarus, Bulgaria, Georgia, Russia, and Ukraine.[[21]](#footnote-22) This phenomenon has been termed the “Silver Tsunami,”[[22]](#footnote-23) a metaphor to encapsulate the larger proportions of populations around the world who will require additional care and assistance, ranging from medical assistance to simple domestic and personal tasks. Given there will be fewer family members and professionals available to provide eldercare services over time,[[23]](#footnote-24) this deviation is expected to put additional pressures on healthcare systems to meet growing demand for services related to aging.[[24]](#footnote-25) Moreover, as women have increasingly entered the workforce over time and around the world, demand for care by paid workers has also increased, as traditionally, the elderly were cared for at home by female family members.[[25]](#footnote-26) While societies have turned to using migrant labour to fill these positions, the number of skilled workers does not meet increasing demand identified worldwide.[[26]](#footnote-27) Consequently, novel solutions like the creation and implementation of robots in various roles related to eldercare have been proposed.[[27]](#footnote-28) Though some robotic solutions will not require an ability to verbally communicate or socialize in a humanlike manner, others will require some degree of skill in this domain, indicating a need for the further development of social robots.

 Aside from caring for elderly patients, social robots will likely be useful for healthcare in general. Moreover, given reflections upon the COVID-19 pandemic, these robots will also be useful for risky or dangerous healthcare situations.[[28]](#footnote-29) In particular, researchers note a demand for robots to perform jobs like measuring patient temperatures.[[29]](#footnote-30) In hospitals, the use of these robots for emotional support, socializing, and information delivery or monitoring also carries the potential to improve healing and recuperation, as research suggests psychological factors like anxiety can delay the duration of post-surgery recovery.[[30]](#footnote-31) Additionally, individuals rehabilitating from a stroke may benefit from physical training accompanied by a social robot, offering support and motivation to individuals required to carry out repetitive tasks.[[31]](#footnote-32) Similarly, social robots may also be useful in pediatric settings, offering emotional support to children and providing a distraction from clinical procedures.[[32]](#footnote-33)

 Social robots may also have a positive effect on health outcomes if they can alleviate social isolation, as feelings of loneliness significantly impact individual well-being.[[33]](#footnote-34) Given the increasing rates of social isolation identified around the world over the last few decades,[[34]](#footnote-35) exacerbated by the COVID-19 pandemic,[[35]](#footnote-36) social robots may provide assistance in this domain as well.[[36]](#footnote-37) Although human social supports are ideal, if robots are able to generate positive outcomes for individuals, these outcomes may be more beneficial over not having a robot at all. Regardless, human-to-human support for individuals, however, ought to remain the norm. That said, specific situations may arise where patients and/or their families can benefit from some degree of support from robotic solutions. Similarly, as the demand for support related to mental health conditions often outpaces the available supply of services, especially in developing countries,[[37]](#footnote-38) social robots may also assist in these domains as well.[[38]](#footnote-39) Overall, however, more research is required to determine the impact of robotic solutions for directly improving mental health outcomes.[[39]](#footnote-40) While it seems likely these robots will provide some degree of social support for individuals in need, it remains to be determined whether these solutions will involve therapeutic approaches which go beyond a friendly conversational partner.

 Demand for social robots is also growing in domains related to childcare and education,[[40]](#footnote-41) especially for those with autism.[[41]](#footnote-42) Researchers have noted a unique opportunity for social robots within educational settings for individuals with autism. In particular, the company LuxAI has developed QTrobot along with an educational curriculum specifically for this purpose.[[42]](#footnote-43) Individuals on the ASD spectrum tend to prefer interacting with objects over people, and generally demonstrate an interest in technology given the predictability of behaviours.[[43]](#footnote-44) Moreover, with robots, social interactions are simplified with fewer behavioural cues to understand and keep track of, potentially reducing feelings of anxiety as a result.[[44]](#footnote-45) Robots are also likely to help educate children with autism as these individuals often require more instruction through repetition than their neurotypical peers.[[45]](#footnote-46) Because robots do not tire nor lose patience with their students,[[46]](#footnote-47) individuals with autism may benefit from interacting with these agents over human counterparts. Indeed, several studies have indicated increased levels of attention and engagement when using social robots over human instructors for learning and developing skills.[[47]](#footnote-48) Given this, however, it is important to mention that autism consists of a spectrum of abilities and challenges, where some individuals may benefit from robot-mediated learning while others might not.[[48]](#footnote-49) Additionally, it remains to be determined whether social skills gained from practice with robots can be successfully applied and incorporated into interactions with humans.[[49]](#footnote-50) Despite the uncertainties, social robots are likely to provide a degree of assistance to some children with autism,[[50]](#footnote-51) indicating an incentive for further research and development in both domestic and childcare settings.

 Additionally, social robots are poised to be useful for other services as well, including customer service; such as in airports and train stations,[[51]](#footnote-52) along with restaurants, theme-parks, tourism, and hospitality.[[52]](#footnote-53) Social robots would be able to assist travellers with several services both related and unrelated to travel, such as baggage-claim and customs for international travel. Furthermore, these robots may be particularly useful for travellers requiring translation assistance, as local signage may not include language individuals are familiar with. Individuals would be able to ask the robot a question in their preferred language, rather than having to translate or speak a foreign language to receive assistance. Ideally, these robots should do more than merely giving directions, and instead, act as a friendly face for the airport or station. This indicates an opportunity for features frequently associated with entertainment settings as well, including the ability to tell appropriate jokes, perform a brief song or dance, or ask trivia questions. In these cases, the robot’s ability to detect emotions would provide it with feedback as to whether the audience’s reactions or experiences engaging with the robot were positive or negative, learning over time as it engages with its audiences.

 Emotional sensitivity, however, is not necessary for all social tasks surrounding customer service, as observed in a hospitality robot developed in Italy. Brillo the bartender robot is able to make drinks and engage in conversation with patrons.[[53]](#footnote-54) In this case, a high degree of emotional sensitivity may not be required, as the robot’s primary task is to efficiently serve drinks in a friendly manner. As such, some social robots may simply appear to be sociable, while others must be able to socialize in a nuanced, intelligent manner, depending on the role it is fulfilling. It seems likely that social robots with a variety of capacities and skill sets will emerge over time, as indicated by market demands. As the breadth of domains in which robots are proven to be useful continues to increase, a greater number of industries will likely find uses for them. If successful implementations continue to indicate a potential to improve client satisfaction, working conditions, and net profits, their adoption and popularity is likely to grow.

 Overall, the presence of global demand, in conjunction with financial incentives, will continue to motivate companies, academic institutions, and other organizations to produce systems capable of fulfilling a variety of roles requiring some degree of communicative and social dexterity. Thus, social robots appear to remain an important technology to develop for various purposes within society. Given the aforementioned demographic needs identifiable worldwide, it seems likely the development of social robots will continue. Due to shortages in the supply of human labour related to care settings, along with an increasing demand for eldercare services, social robots are poised to become a solution for addressing these issues. Though governments and institutions may regulate the ways in which robots can be used or implemented, it appears that demand will continue to drive their development in some fashion for the foreseeable future.

1.2 – Requirements for Social Roles

Given this interest in social robots, these agents are likely to become integrated within societies around the world. For them to be deemed acceptable by human populations, however, they will need to have certain capacities to be useful and safe. To determine the scope of these capacities, it is important to understand the necessary elements for social robots. To some, these agents simply consist of an expanded version of regular industrial robots with a *social interface*, where visual features provide signals for acting in specific ways with these agents.[[54]](#footnote-55) On the other hand, some envision social robots as specialized systems which learn and develop over time, building on previous knowledge to perform complex skills similarly to young humans. This approach can be observed within the domain of *developmental robots* as an outcome of AI research over the 20th century, as discussed further in the following chapter. In general, a variety of architectures or approaches will likely emerge over time, giving rise to different kinds of social robots in the future.

 For robots to fulfill roles typically performed by humans, they will require certain capacities to interact with and be accepted by the general public.[[55]](#footnote-56) This can be achieved by recreating aspects of human cognition in computer code. To act in a humanlike manner, robots will need to perceive and express emotions in ways which are appropriate for specific contexts, as well as communicate through language and behavioural cues. Moreover, these robots must be able to recognize, remember, and learn about other agents they interact with.[[56]](#footnote-57)

 When polled, individuals rate capacities for empathy, logical thinking, and explanation as some of the most desirable capacities in social robots.[[57]](#footnote-58) In another study investigating variables for the acceptance of social robots, similar themes also emerge as survey results indicated factors like usefulness, sociability, companionship, and behavioural control were rated as important characteristics.[[58]](#footnote-59) Additionally, people have expressed interest in a social robot’s ability to work with others in a friendly manner.[[59]](#footnote-60) Experiments with social robots indicate people engaged with emotionally expressive robots are more likely to rate the interaction as highly satisfying, in comparison to interactions with less expressive robots.[[60]](#footnote-61) Because emotion is an important aspect of conversation and socialization, individuals will likely prefer to interact with robots whose behaviours respond appropriately to one’s mood or emotional state. Furthermore, robots deployed in public settings must be easy to use and engage with,[[61]](#footnote-62) where visual appearances adequately indicate the range and style of behaviours performed by the agent.[[62]](#footnote-63) Overall, this range of characteristics suggests individuals want social robots to act as humanlike as possible, making their behaviours easier to understand and interact with.

 If these expectations are not met, users may consider social robots unhelpful or inappropriate.[[63]](#footnote-64) Over time, if disappointment frequently arises from a mismatch in expected ability and actual ability, individuals may begin to lose trust in social robots more broadly. Failures to portray a robot’s specific abilities risks the dissolution in human-robot cooperation and relations in the future. This mistrust introduces the potential to negatively impact human populations if robots are to become widely implemented, especially for safety-critical tasks such as search and rescue operations.[[64]](#footnote-65) Moreover, studies on human trust suggests individuals are concerned about how well these robot are attuned to safety and security, and whether these robots are able to independently perform tasks. Therefore, it seems social robots will be required to act in a humanlike manner to facilitate cooperation with humans.

 Thus, in a variety of social roles, interactions with robots must be as intuitive and familiar as possible. To be successful, social robots are required to perform a wide range of behaviours to serve and work with people. The challenge arises from the nature of these interactions, as social situations are highly dynamic and have the potential to be unpredictable. Furthermore, language relies on words associated with contextual factors to convey certain ideas, in addition to sounds and behaviours which are less linguistic in nature, such as body language. Social robots will likely need the ability to learn about aspects of the world to act appropriately in a reliable manner, drawing on previous experience to determine the best course of action in a given scenario. To do so, the robot must be able to incorporate forms of feedback from the environment to adjust their behaviours accordingly, similarly to people and animals. In this way, humanlike behaviours can be created in machines which sufficiently produce capacities and behaviours required for social interactions.

1.3 – Human Communication

At first glance, it is clear robots will need to have an understanding of language and social cues if we want them to adopt social roles and interact with humans. A robot’s ability to comprehend human utterances and behaviours, however, relies on some degree of knowledge about aspects of its environment or the wider world to know what a human might be referring to.[[65]](#footnote-66) Moreover, while comprehension is a significant aspect of socialization, an effective robot will need to respond appropriately through a variety of different sounds, words, and bodily expressions.[[66]](#footnote-67) Non-verbal behaviours may consist of gestures, body movements, eye contact, and facial expressions.[[67]](#footnote-68) All together, the acts themselves and the content of linguistic expressions act as cues which provide information about what the robot is conveying or referring to. While language involves the application of a discrete formal system, it also involves *pragmatics*, or the elements of expression not represented by the language itself.[[68]](#footnote-69) This implicit information is embedded in an expressive act, such as the use of specific words or sounds, vocal pitch and amplitude, and speech pauses.[[69]](#footnote-70) Implicit acts of communication may also be supported by body language and gestures, particularly hand gestures signifying actions or intentions. These subtle methods of communication appeal to features of situational context, as variables such as the current place and time are often relevant for communicative efforts.[[70]](#footnote-71) Currently, text-based agents like *large language models* (LLMs) do not appeal to information related to situational context, introducing limitations which embodied social robots may be able to overcome.

 Another element to consider for social robots is the requirement of joint attention for working with others toward a shared goal.[[71]](#footnote-72) Both robotic and human agents are required to coordinate their intentions or plans in order to execute behaviours appropriate for producing desired outcomes. This involves a consideration for what the other agent is likely attending to or thinking about, requiring them to align their understanding of the goal and the necessary actions for accomplishing it.[[72]](#footnote-73) Robots are thus not only required to have sufficient background knowledge about the world, but are also required to skilfully reason about the ways in which others see the world.[[73]](#footnote-74) Robots will be required to understand the reasons why individuals perform certain actions, and to make assumptions about what others are directing their attention toward.[[74]](#footnote-75) Therefore, it must have an ability to interpret human behaviours to understand what they are focusing on and their larger goals, such that the robot can coordinate its own behaviours to act appropriately. Otherwise, confusion and misunderstandings are likely to emerge, and if user frustration results, it may impede further cooperation with the robot.

 Together, this collection of skills and requirements for social robots suggests human communication is more complex than merely combining semantics and syntax, requiring robots to master a variety of verbal and non-verbal abilities. Since communication is highly complex and required in social robots, further research and development is necessary. From this analysis on the complexities of human communication, it appears several abilities are needed if these robots are to be useful for our purposes. Given the financial incentives present for developing useful applications, the necessary research and development for generating robotic solutions for a variety of purposes is likely to continue into the foreseeable future.

 Even if robots are one day able to meet these requirements, there is still an important aspect about human communication to consider. Interactions with social robots will remain a mere simulation of human interactions, as social situations involve reciprocity and cooperation.[[75]](#footnote-76) In humans and animals, these actions involve underlying motivations which are not present in machines, as robot actions are governed by instructions written by programmers. That said, robots can be built to have motivations, however, this requires a different approach than the one used today, as will be discussed in Chapter 4.

 According to Johanna Seibt, Founder and Director of the Research Unit for Robophilosophy and Integrative Social Robotics (RISR),[[76]](#footnote-77) a problem arises when we consider the foundations of social interactions more broadly.[[77]](#footnote-78) She claims we cannot treat human-robot interactions as fictionalist analogues of human interactions because the concepts used in these fictionalist accounts do not apply to robots. This is because sociality stems from “joint attention to basic patterns” which begins in childhood, where providing responses and engaging in turn-taking rely on “pre-conscious” abilities intrinsic to human minds.[[78]](#footnote-79) Despite attempts to recreate these capacities in robots, the result is a *model* which imitates the phenomenon identified in human-human interactions. Therefore, human-robot interactions are, at best, “asymmetric simulated social interactions,” where even a perfectly simulated interaction remains ontologically distinct from the human-human interactions the model aims to recreate.[[79]](#footnote-80) It will become exceedingly important to keep this idea in mind as robots continue to advance, as humans have a tendency to anthropomorphize objects[[80]](#footnote-81) and ascribe to them abilities that they do not possess. Although they may *simulate* certain abilities, robots do not care about their own existence or existence as a social entity. As a result, a robot is not a true social being, as sociality is an evolved capacity for the advantage it provides for the organism’s own survival and reproduction. Given that a robot is a machine, it cannot demonstrate true sociality as it does not care about its own existence nor the existence of others.[[81]](#footnote-82) Robot behaviours are generated by a mechanistic sequence of events executed without awareness, a topic which will be discussed in later chapters.

 It is important to study the physical and functional foundation of robot behaviours, as our understanding of their constitution impacts the way we think of them and their abilities. If human individuals believe computer behaviours are indicative of certain capacities which are absent in reality, a risk of harm to human populations is subsequently introduced. These harms are likely to be emotional or psychological in nature, as humans may develop unrequited or one-sided attachments to artificial agents designed to capture their attention. Chatbots and cellphone apps designed as “AI girlfriends” or other romantic interests are currently being developed and growing in popularity, particularly in response to the “loneliness epidemic” observed in many countries around the world.[[82]](#footnote-83) Because social robots and other AIs are not living beings, they are not invested in themselves as agents nor the relationships they develop with others. Animals and other humans are able to develop meaningful relationships because of their mutual gain from the arrangement, while robots are not even invested in their own survival. This distinction is highly significant for emotional well-being, as humans are often motivated to become emotionally attached to other living beings, going so far as to erroneously anthropomorphize machines.[[83]](#footnote-84) On top of these emotional harms, physical harms may also be introduced in situations where a failure of understanding results in injury to human individuals. An inability to understand contextual cues, both verbal and behavioural, may have effects which lead to physical harm in addition to psychological or emotional harms.

 This chapter has argued for an increasing likelihood of the widespread implementation of social robots, given identifiable needs for them to serve in roles typically fulfilled by humans. Additionally, it is argued that social robots will be required to understand the meanings of words and behaviours used by people to communicate with one another. While a robust understanding of the world and its features is a significant aspect of this capacity, the interpretive skills required for understanding various behaviours will be just as important. For example, an emotion can be communicated through the use of language but also through visual cues like facial expressions.[[84]](#footnote-85) In addition to being able to understand what humans are communicating, social robots will also need to produce language and behaviours which people can understand and deem appropriate. This will involve choosing the correct words for conveying a specific meaning but also an ability to perform supplementary behavioural cues which further support or contribute to the message or idea communicated. Together, an ability to understand and communicate a variety of social cues and linguistic elements constitute the core capacities required for social robots. If they fail to meet these requirements, human individuals may not enjoy interacting with them, impacting their overall acceptance as a result. In certain contexts, inadequacies in social robot performance may negatively impact human life; for example, patients in healthcare settings may have their dignity infringed upon or safety threatened if a robot does not treat them distinctly from an inanimate object. Therefore, the stakes for social robots are rather high as simulated forms of social interactions have the potential to deeply affect emotional, psychological, and physical well-being.

 Considering empathy is rated as a highly desirable capacity in social robots,[[85]](#footnote-86) especially in healthcare settings,[[86]](#footnote-87) it is important to examine what empathy involves and whether this is tenable goal. Given the pressing need for healthcare workers, social robots are likely to be found in roles related to care and human interaction in the future, making empathy a significant component of social robot behaviour. Although robots may one day act as if they can understand how an individual is feeling, given our tendency to anthropomorphize robots, we should carefully consider whether those projections are accurate. It will be important to ensure our beliefs about a robot’s abilities are accurate so as not to attribute these machines with capacities they do not possess. This is accomplished by the robot’s form and appearance, as it provides an indication to users the kinds of behaviours or abilities it is likely to perform.[[87]](#footnote-88) For example, a humanoid robot indicates humanlike abilities, where the inclusion of a smiling mouth suggests a friendly, communicative agent. A mismatch between human expectation and robot functionality has the capacity to disappoint or confuse users, potentially leading to negative experiences which decrease the likelihood of subsequent use or interaction. Moreover, significant harms can be introduced if humans rely on robots for behaviours or tasks which they cannot fulfill. If robots are to care for humans in a respectful manner, patients, staff, visitors, and other personnel must be aware of social robot capabilities and limitations. I will argue that existing robots exhibiting emotions involve a simulation as the robot is unable to truly understand what emotions are. This is in virtue of the relationship between the robot’s body and its mind, as I aim to explain in this dissertation. In regards to empathy, the question about whether these outcomes are even possible must be raised. To answer this question, however, a separate inquiry must be undertaken prior to this investigation: what is empathy and how does it manifest? The next chapter explores and provides the philosophical history of this human capacity, in addition to an investigation into the scientific literature on theory of mind to determine whether social robots will one day be capable of acting in such a manner.

Chapter 2 – Analyzing Empathy

 In this overview, some of the philosophical and scientific literature on empathy is outlined. Within this literature, two views on *theory of mind* have historically characterized how acts of empathy occur. Referred to as *theory theory of mind* and *simulation theory of mind*, each attempts to explain different facets of perspective-taking required for empathy. Both theories of mind, however, are insufficient for fully encapsulating what empathy involves, despite their significant contributions. After identifying the short-comings of each theory, I discuss a preferable third option called *interaction theory* which accounts for contextual variables impacting the accuracy of an act of empathy.

2.1 – Empathy as a Philosophical Concept

The philosophical literature on empathy begins in the late 19th century and involves a few related but distinct ideas. Various positions and theories about the mind and human behaviour have influenced the way philosophers characterized empathy throughout history. With scientific advancements enhancing our capabilities to study the brain, philosophical theory or *folk psychology*, as described by the literature, became insufficient for explaining empathy. Eventually, the discovery of mirror neurons gave new life to the study of empathy, as brain activity could now account for ideas or theories generated from philosophy. Although controversy surrounding the existence of special mirror neurons has arisen since their discovery, the activity these cells generate provides insight into how imitation, mimicry, and empathy are accomplished. That said, these empirical findings and the resulting *simulation theory* [*of mind*] remains insufficient for a complete understanding of what empathy is and how it is generated within individuals. Though our understanding of empathy has improved, the debate continues regarding the specific details and facets of empathy. Considerable work on establishing a conceptual foundation for empathy has identified numerous important elements or actions involved,[[88]](#footnote-89) hence there is much discussion on this topic which cannot be explored in this chapter. The reason for this is because acts of empathy involve both cognitive and affective elements.[[89]](#footnote-90) While *theory theory* [*of mind*] seems to adequately articulate many of the cognitive aspects of empathy, and *simulation theory* is able to explain many affective elements,[[90]](#footnote-91) together, these accounts still do not provide a sufficient explanation for empathy. As such, an alternative perspective is required for a comprehensive theory of this remarkable capacity.

 The term ‘empathy’ was introduced in 1909 by English psychologist Edward Titchener, a student of Wilhelm Wundt,[[91]](#footnote-92) as a translation of the German word *Einfühlung* or “feeling into.”[[92]](#footnote-93) *Einfühlung* was introduced as a technical term within the field of Aesthetics by Robert Vischer in 1873, and eventually popularized byTheodor Lipps to describe a process of projection.[[93]](#footnote-94) Lipps describes aesthetic experiences as involving the use of a specific perceptual ability which causes us to imitate movements and expressions as perceived from elements of our physical environment.[[94]](#footnote-95) According to Lipps, we project a part of ourselves into or onto that object, and how we feel in this projection informs our attitudes or thoughts about the object itself.[[95]](#footnote-96) We tend to feel good about an object if it possesses a form which, when aligned with our own human body, contributes or generates a kind of energy or “vitality” within us.[[96]](#footnote-97) Because this projection occurs subconsciously, we ascribe the associated feelings onto the object we are observing, attributing them to the object rather than to ourselves. Thus, when viewing another person, Lipps describes an innate tendency to experience oneself in their perceived state, where we experience the other’s feelings as our own due to this projection.[[97]](#footnote-98) By using our own mind as an analogy for understanding another’s mind, we are able to know about the inner experiences of others.[[98]](#footnote-99)

 It has been speculated that Lipps may have been building off David Hume’s work given his familiarity with *A Treatise of Human Nature* after translating it into German.[[99]](#footnote-100) In it, Hume discusses ideas associated with mental projection: “The minds of men are mirrors to one another.”[[100]](#footnote-101) Hume describes a transmission of emotion between one person and another where the observer notices a distinction between his own feelings and the feelings of another.[[101]](#footnote-102) The term he uses, however, is not ‘empathy’ but ‘sympathy’ to describe a process where the observation of behaviours provides an idea about the affective state of another. To Hume, *ideas* generally follow from *impressions*, where impressions refer to perceptions and sensations, while ideas consist of “faint images” of perceptions for thinking and reasoning.[[102]](#footnote-103) During instances of empathy, Hume specifies that this relation is reversed, where impressions follow from ideas:

 When any affection is infus’d by sympathy, it is at first known only by its effects, and by those external signs in the countenance and conversation, which convey an idea of it. This idea is presently converted into an impression, and acquires such a degree of force and vivacity, as to become the very passion itself, and produce an equal emotion, as any original affection. However instantaneous this change of the idea into an impression may be, it proceeds from certain views and reflections, which will not escape the strict scrutiny of a philosopher, tho’ they may the person himself, who makes them.[[103]](#footnote-104)

 These ideas of empathy as ‘sympathy’ seem to have also influenced the perspective of Adam Smith as reflected in his work *The Theory of Moral Sentiments*.[[104]](#footnote-105) For both Hume and Smith, ‘sympathy’ provides a way to explain why individuals driven by self-interest would be concerned for others and the society they live in*.*[[105]](#footnote-106) While Hume’s view focuses on lower-level abilities which reflect the affective states of others, Smith’s view involves a higher-level or more cognitive approach, articulating an ability to imagine oneself in another’s situation.[[106]](#footnote-107) To know how another feels, according to Smith, we project ourselves into their position or point of view to reason about their actions or behaviours. While this reasoning process relies on introspection, it is performed with full awareness to generate a top-down process, differing from Hume’s understanding of empathy as a subconscious, bottom-up process.[[107]](#footnote-108) Thus, the debate between whether our capacity for empathy is more cognitive or affective in nature is present in the origins of the identification of the capacity itself, where the term used to describe this ability is not the one we use today.

 To avoid confusion, however, it is important to briefly articulate the contemporary usage of ‘sympathy’and ‘empathy’. This is not an easy distinction to draw, especially considering historical uses of ‘sympathy’ for describing abilities which have since been considered as empathic in nature. It has been suggested that sympathy is associated with feelings of sorrow or concern for another,[[108]](#footnote-109) however, ‘sympathy’ has also been associated with emotional contagion, where the perceived states of others are adopted as one’s own.[[109]](#footnote-110) Empathy, on the other hand, is an *other-oriented* emotional response where the perspective of another person is adopted by an observer, aiming to experience thoughts and feelings as if they were the other individual.[[110]](#footnote-111) It can be characterized as “feeling *as*” rather than “feeling *for*” another person.[[111]](#footnote-112) While this distinction between sympathy and empathy may oversimplify a richer understanding of this conceptual relationship, for the purposes of this discussion, we can think of the difference as residing in to whom these feelings belong. If an observer is adopting the feelings of others to understand or experience the feelings of another, they are demonstrating empathy. Alternatively, if the observer attributes the feelings as belonging to another, and instead modifies their own emotional state in response to the experiences of another person, it can be characterized as sympathy.

 Lipps’s work on *Einfühlung* would go on to influence the work of others, including Titchener in his study of psychology,[[112]](#footnote-113) but also in the writings of phenomenologists including Martin Heidegger,[[113]](#footnote-114) Edmund Husserl,[[114]](#footnote-115) Edith Stein,[[115]](#footnote-116) and Max Scheler.[[116]](#footnote-117) Criticism of Lipps’s work included a dissatisfaction with his appeal to instinct and a lack of empirical evidence. An additional criticism involves an inability to explain how one’s own experience generates an understanding of how another person may experience that same stimulus, given the various differences between individuals.[[117]](#footnote-118) Similarly, Scheler notes Lipps’s account does not consider the accuracy of this projection, and whether our understanding of another can be justified given its origins in subjective experience.[[118]](#footnote-119) Phenomenological accounts of empathy have contributed to further identifying features of empathy and how it functions, however, over time, they would fall from favour given their independence from empirical evidence.[[119]](#footnote-120) As the 20th century saw a rise in the development of scientific methodologies for studying the mind, simply theorizing about empathy was no longer sufficient for establishing an explanation of this ability.[[120]](#footnote-121) Although these theoretical accounts were foundational for developing a philosophical understanding of empathy, the concepts it relied upon were derived from an outdated methodology and considered to belong to the domain of folk psychology.[[121]](#footnote-122) Despite the decline of their popularity, these philosophical theories still provide an essential perspective for analyzing and interpreting scientific data of behaviour and neural activity, and as such, are still required for guiding discussions on what empathy involves and how it is achieved.[[122]](#footnote-123)

 *Simulation theory* suggests empathy is accomplished from the act of appealing to one’s own experiences to subsequently imagine how another person may experience the same stimulus or situation. This is facilitated by the general structural and functional similarities between the minds and brains of human individuals.[[123]](#footnote-124) Consequently, it has been described as a “process-driven” rather than a “theory-driven” procedure, as it requires individuals to perform cognitive tasks to know what another is feeling.[[124]](#footnote-125) To contemplate how or what another person is feeling, we use our own perspective as a model for how another may see the world, using the same causal mechanisms when expressing our own feelings. Although Lipps’s views were introduced prior to any empirical evidence on the matter, this early *simulation theory* gainedrenewed interest in the late 1980’s when evidence for the existence of mirror neurons was discovered.[[125]](#footnote-126) Researchers noticed a brain region in macaque monkeys containing cells which fire while observing the actions of others and also when performing an action.[[126]](#footnote-127) This neural activity seemed to indicate a “common representation format” which enables individuals to mimic or imitate the actions of others.[[127]](#footnote-128) It was thought these cells accomplish this through genetic encoding, where natural selection gave rise to unique cells which enable individuals to understand the goal the other’s actions aim to achieve.[[128]](#footnote-129) By coding for actions by the effects they produce, individuals are thus able to recall or imagine an action by anticipating its effects.[[129]](#footnote-130) As such, these neurons generate an automatic and relatively simple mechanism for mimicking others, providing an ability to imitate actions and learn new behaviours through observation.[[130]](#footnote-131)

 Since then, however, a debate surrounding these cells has emerged to indicate an alternative perspective. This view argues that instead, mirror neurons are not a unique form of neuron but another type of associative neuron, the ones used in classical and operant conditioning.[[131]](#footnote-132) Consequently, when individuals observe the actions of others, they learn to respond with particular motor programs accordingly, generating an association between the two.[[132]](#footnote-133) For example, experimental evidence indicated behaviours could be retrained in response to observed actions, as individuals could be trained to unintentionally move their little finger after observing the movement of an index finger.[[133]](#footnote-134) Furthermore, when a stimulus is associated with two or more actions, the context in which behaviours are observed determines which action is subsequently performed.[[134]](#footnote-135) Moreover, additional research on mirror neuron functionality indicates that rather than representing high-level information such as the intended effects of actions or the goals they aim to produce, mirror neuron activity instead represents low-level information such as the style of grip observed by the hand of another.[[135]](#footnote-136) Therefore, from an array of experimental evidence which contradicts or complicates initial assumptions on mirror neurons, our current understanding of these cells has shifted from genetically-determined neurons exhibiting unique behaviours, to common associative ones identifiable throughout the brain. Though researchers and publications may still refer to “mirror neurons,” the cells they are referring to are not functionally distinct, behaving in ways which no other neurons do, but rather consist of associative neurons found elsewhere in the brain.

 In addition to deliberate, intentional mimicry and imitation, the ability to imitate others occurs on subconscious levels as well. Evidence indicates a physiologically-grounded tendency to mimic others during interactions, where we align our facial, vocal, and postural expressions to those demonstrated by others.[[136]](#footnote-137) Moreover, research suggests mimicry can be established on deeper physiological levels, where *autonomic* mimicry arises between individuals to synchronize bodily processes like heart rate and breathing rhythms.[[137]](#footnote-138) This synchronization suggests emotional contagion serves as a foundation for empathy and other prosocial behaviours, as mimicry contributes to feelings of similarity and closeness, influencing how we judge or perceive others.[[138]](#footnote-139)

 Thus, from this examination of mirror neuron activity, *simulation theory* seems to identify a physiological foundation for explaining how empathy is generated. Mimicry and imitation provides insight into other’s feelings, as we use our own emotional responses as an analogy for the feelings of others.[[139]](#footnote-140) Although some mirroring processes are automatic, others can be intentionally undertaken to recreate an experience in an effort to align oneself with another.[[140]](#footnote-141) Considering this evidence for mirror neuron activity in this larger sense, is it the case that empathy can be fully explained by *simulation theory*? The third section of this chapter demonstrates why this is not exactly the case, and that additional considerations are required for a full explanation of empathy. Before doing so, however, it is necessary to discuss the connection between *simulation theory* and conclusions drawn from evolutionary biology. This relation indicates a continuity between human and animal behaviour to suggest the social significance of this perceptual capacity.

2.2 – Empathy as an Evolutionary Outcome

Although initially discovered in macaque monkeys, mirror neuron activity has been subsequently identified in humans, indicating we are not unique in our ability to mimic and imitate others. While affective communication and emotional contagion have been identified in birds and fish as well,[[141]](#footnote-142) empathy as an other-oriented perspective appears to exist in several mammalian species.[[142]](#footnote-143) In a model proposed by de Waal and Preston, empathy is conceived as involving three layers, building on emotional contagion and motor mimicry to generate an ability which adopts the perspective of another and potentially provide comfort.[[143]](#footnote-144) These higher forms of empathy have been identified in other apes like chimpanzees and bonobos, but also in elephants, mice, and canines.[[144]](#footnote-145) The evolution of these abilities is likely due to their ability to promote cooperative behaviours by generating a shared perspective for ensuring safety and executing goal-directed behaviours.[[145]](#footnote-146) Therefore, empathy is an advantageous trait which evolved in many social species since it helps individuals learn about emotions of others, as well as a means for organizing and securing groups of individuals.

 In their paper titled ‘Mammalian empathy: behavioural manifestations and neural basis’, de Waal and Preston articulate a process which describes how empathy emerges from its foundation as emotional contagion.[[146]](#footnote-147) It is important to investigate this process-model because it supports the theory of empathy which I argue for in the following section. The process begins with emotional contagion, where an observer adopts the emotion as perceived in another, creating a shared affect which serves as a foundation for empathy to emerge. At this stage, for the observer to consider how another feels, they must control their own feelings through emotional regulation, shifting their attention from their own feelings to the perspective of another instead. Without inhibiting or ignoring their own feelings of distress through self-regulation, individuals may become too distracted to provide assistance or respond to another.[[147]](#footnote-148) The understanding derived from this other-oriented consideration can be used to perform actions which reduce feelings of distress, where the subsequent relief is then shared by the observer through a second occurrence of emotional contagion. As such, the initial distress picked up from another and felt by the observer is eventually reduced, creating an intrinsic reward for acting altruistically. Moreover, evidence from experiments involving chimpanzees and human children suggests this intrinsic reward operates independently from extrinsic rewards, where the act of providing individuals with rewards for assistance does not influence their helping behaviours.[[148]](#footnote-149) Interestingly, young children seem to demonstrate a reduction in helping behaviours when extrinsically rewarded, though this effect does not apply to verbal rewards like praise, which instead, seems to increase the inclination to help others.[[149]](#footnote-150) Thus, intrinsic rewards serve as a motivator for performing actions which assist others; however, to do so, individuals must successfully turn their attention away from their own internal states to consider the emotions of another. In doing so, individuals are able to understand how another is feeling, where emotional contagion assists with empathy but does not guarantee empathy will occur.

 From this discussion of empathy as a process, it becomes apparent that while the discovery of mirror neurons has significantly contributed to our understanding of empathy, they alone are not sufficient for explaining or describing what empathy involves. The act of simulating within oneself how another might be feeling does not guarantee that these interpretations are correct. We may interpret behavioural cues as meaning one thing while in fact, they mean something else entirely. This may be due to interpersonal unfamiliarity, however, it may also arise as a consequent of sociocultural norms. As such, there will always remain the question of how well our intuitions or projections accurately represent the inner states of another. Although we are able to imitate behavioural cues and simulate within ourselves the perceived states of others, we may still be incorrect in our interpretations and understanding of another.[[150]](#footnote-151) There may be instances where we may find ourselves uncovering limitations in our ability to project or infer in certain instances when empathy is required, and *simulation theory* alone does not address how using one’s own perspective as an analogy of another’s mind results in an accurate understanding of the other.[[151]](#footnote-152) For example, if the observer has never experienced the death of a loved one, they may find it difficult to know exactly how another is feeling in that circumstance. Other limitations may arise from sociocultural differences, as the meanings of others’ behavioural cues can differ from expectations and assumptions, impacting the way these cues are interpreted.[[152]](#footnote-153) In particular, coping with or reacting to a death may be perceived or experienced in a variety of differing ways, based on factors like sociocultural norms, beliefs, and values. For death especially, religious beliefs may play a role in how death is experienced in the loss of a loved one. Therefore, to know how another feels in this situation, the observer must appeal to their knowledge of the other person to know how these feelings are experienced, independently of their own interpretations or reactions. Overall, while mirror neuron activity indicates a mechanism for responding to the emotional states of others, a degree of knowledge is still required to accurately perceive behavioural cues and adopt emotional states accordingly. *Simulation theory* is therefore insufficient for fully explaining empathy, as inner representations alone do not provide enough information to know how another is feeling.

 To understand how this theoretical knowledge of other minds is generated, philosophical discussions have turned to findings from developmental psychology.[[153]](#footnote-154) Experimental evidence suggests that infants as young as 2 weeks are able to imitate specific facial movements observed in adults,[[154]](#footnote-155) demonstrating an innate ability to generate new behaviours through observation. Internal representations of actions and emotions are created by associating the actions of others with how these actions are subjectively experienced.[[155]](#footnote-156) At around 6 weeks of age, infants begin engaging in “proto-conversations” with others through smiling and mimicking facial movements, where these exchanges continue to develop associations between perceived actions and subjective feelings.[[156]](#footnote-157) From these emotional exchanges, infants develop an ability for *joint attention* where they are able to shift their focus to an object being looked at by another.[[157]](#footnote-158) This ability provides a foundation for intersubjectivity and a shared understanding of the environment and its features. Along with social learning, these emotional exchanges generate emotional bonds between children and caregivers which facilitates further learning as children continue to grow and explore. At around age 1, children are capable of demonstrating a concern for others, and around a year and a half, can offer consoling behaviours to people in distress, indicating empathy is a capacity which emerges early in life.[[158]](#footnote-159) With an acquisition of language and conceptual knowledge, children expand their understanding of how other minds operate in different situations, especially as they continue to socialize with individuals outside of their own family. At about age 3 or 4, children develop an ability to differentiate between their own perspective and the perspectives of other people, as per experiments using *false-belief tasks*.[[159]](#footnote-160) This experimental paradigm involves a child and another person in possession of an object they have placed in a specific location. When the child witnesses the experimenter move the object to a new location, while the other person is not watching, they are then asked where they think the other person believes the object is, in the previous location or the new location.[[160]](#footnote-161) Children who think the other person believes the object is in the new location are thought to *not* possess a theory of mind, as they conflate their own knowledge with that of another. It is debated, however, whether this test is suitable for drawing conclusions on theory of mind.[[161]](#footnote-162) Regardless, it seems our ability to understand the minds of others, to some degree, begins early in life and continues to develop over childhood as individuals encounter new situations, experiences, and types of people. Interacting and socializing with others informs individuals of the ways in which the perspectives of others can differ from their own, especially in those from diverse sociocultural backgrounds. Given that the frontal regions of the brain do not fully mature until late adolescence, it has been suggested a more robust form of empathy takes years to develop.[[162]](#footnote-163) This suggestion is the result of neural-imaging studies which suggest the brain regions used differ between adults and adolescents. Therefore, developing an ability to empathize with others involves many years of learning and practice, beginning with imitation and joint attention to establish a cognitive foundation required to support higher-cognitive functions. Included in this set of capacities is a repertoire of social knowledge established through interacting with other people of varying personalities and backgrounds.

 To summarize the main debate in the philosophical and empirical literature on empathy, while *simulation theory* explains how we are able align our own feelings with the perceived emotions of others, *theory theory* describes an approach which considers the way the observer’s knowledge facilitates or clarifies our understanding of others’ behaviour. Together, these two theories reflect the relationship between conscious and subconscious processes, where neuronal activity occurs subconsciously and the application of knowledge or theory requires conscious effort. Furthermore, knowledge and theory are acquired from years of experience and practice, arising from interacting socially with others to develop these cognitive abilities. Activity from neuronal processes, on the other hand, enables an ability to imitate the actions of others like facial reactions and behavioural cues. These subconscious processes facilitate acts of empathy by aligning emotional states, where individuals may also appeal to theory or knowledge to augment perceptual information to know how another is feeling.

 Although *simulation theory* and *theory theory* contribute important perspectives to establishing a better understanding of ‘empathy’, there is still the question of why or how an act of empathy may be accurate or inaccurate. An adequate theory of empathy must also account for cultural or individual variables, where the ways individuals see and experience the world plays a role in their emotional and cognitive reactions to it, including the states of other people. A comprehensive account of empathy should be able to describe why a particular act of empathy is inaccurate or inappropriate. To accomplish this, a mechanism or procedure is required to understand how an act of empathy fails or succeeds. To meet this requirement, the following section introduces an alternative theory of empathy which accounts for accuracy by focusing on the specific, contextual interaction between two individuals.

2.3 – Empathy as Context-Dependent

This section outlines *interaction theory* as an alternative to *theory theory* or *simulation theory* and argues that context serves as a significant variable for determining how or when acts of empathy are accurate. Given that empirical literature uncovers a particular process for how empathy occurs, it follows that we should conceive of empathy as a process involving the interaction between two or more individuals. If an individual is inaccurate in their ability to know what another feels, it may be due to a number of reasons, one of which being a lack of familiarity or understanding of the other. By closely examining the contextual components involved, the significance of these factors involved becomes more apparent. The literature on empathy often mentions “the situation” or “the feeling,” where these details are considered in light of the individuals involved, the setting or location, as well as other factors such as initial stimuli, related information, and additional behavioural cues. To know how to respond in a given context, cognitive skills must be developed through repeated experiences and ongoing practice between a variety of different individuals and perspectives. Therefore, context plays a significant role in determining how and when acts of empathy are accurate or inaccurate.

 As proposed by Shaun Gallagher, *interaction theory* provides an alternative view on how we perceive and encounter others. He describes it as adopting a second-person perspective rather than a first-person perspective, an internal representation, nor a third-person perspective, an observation.[[163]](#footnote-164) Instead, the second-person perspective is a subjective point of view oriented outward rather than inward and toward another person in an attempt to understand, communicate, or interact with them.[[164]](#footnote-165) Rather than focusing on one’s own experiences in a first-person point of view, a second-person perspective is directed outward and towards another to establish an intersubjective understanding of the world for the sake of communication.[[165]](#footnote-166) In contrast, the third-person perspective aims to see beyond a subjective point of view to understand or describe events in a manner independent of how they appear within the first-person perspective.

 An example of these three perspectives can be demonstrated by a situation where individuals living in Toronto encounter a book written in Simplified Chinese. The statement, “this text is illegible” may be true for one person while simultaneously being false to another, provided they understand the language. From the first-person perspective, the truth of the statement depends on the individual uttering it. For the Torontonian who only speaks English, in this case named Bill, the statement will be true. Bill has a friend named Li who recently moved from Beijing. When Bill considers this statement from Li’s perspective, the second-person perspective, the statement is false as Li can read and write Simplified Chinese. From a third-person perspective, this statement is false, given that individuals exist in the world who can read and write Simplified Chinese. Overall, the truth of the statement depends on the person is uttering it, however, from a third-person perspective, its truth-value depends on states of affairs which are independent of the speakers asserting it.

 The second-person perspective best describes how empathy can be produced because it takes into account the viewpoint of another person. Though this perspective may differ from one’s own, individuals are able to consider aspects of the world from an alternative point of view. This enables them to consider how another experiences a particular situation, even when their own feelings about it differ from those of another.

 Although we may appeal to simulations or theories to understand others, Gallagher believes this rarely occurs because, in most cases, we are able to able to understand others without having to simulate their internal states or appeal to a theory.[[166]](#footnote-167) Instead, as we engage with others in social or pragmatic activities, we are normally able to immediately perceive the meanings or intentions behind the behaviours of others, a capacity which is developed over childhood.[[167]](#footnote-168) Gallagher suggests that mirror neuron activity is a part of a broad network of neuronal processes which underlie a form of “intersubjective enactive perception.”[[168]](#footnote-169) By this, he means a “non-articulated immediate perception of the other person’s intentional actions” which is active and embodied, rather than a passive processing of sensory input data detected in the environment. This suggestion is based on evidence from developmental psychology, where evidence indicates infants are able to follow the gaze of another, suggesting an inherent recognition and understanding of this behaviour as meaningful or goal directed.[[169]](#footnote-170) Infants usually demonstrate a keen interest in activity or actions arising from humans over non-living things, as well as an inherent interest in faces over objects.[[170]](#footnote-171) As such, it suggests they can identify subjects and beings like themselves, a capacity which facilitates learning about the minds of others.[[171]](#footnote-172) The ability to follow another person’s gaze establishes an intersubjectivity directed at understanding what others might be referring to.[[172]](#footnote-173) The shared understanding produced by this intersubjectivity allows children to learn about objects being looked at by others.[[173]](#footnote-174) This perceptual ability enables us to understand what others are feeling and perhaps thinking about, however, this ability is not infallible. To correctly interpret cues from another requires one to draw on a “communicative and narrative competency” or conceptual framework which is learned through childhood within a particular sociocultural context and used to explain the meanings of behaviours.[[174]](#footnote-175) Within an act of empathy, this framework can be appealed to if additional information is required to understand of what someone else is feeling within a specific situation or context.[[175]](#footnote-176)

 *Interaction theory* is thus the preferable theory for empathy because it situates an internal cognitive process within a wider interpersonal interaction. As such, it is associated with a particular setting or context and specific individuals with unique backgrounds. *Interaction theory* can describe why acts of empathy can be accurate or inaccurate by considering the presence of contextual variables, either subconsciously or through deliberate consideration, where a particular exchange between individuals may generate errors in understanding given a variety of factors. An expression or behaviour may be perceived as ambiguous in its meaning, requiring the observer to appeal to knowledge or information about the individual in question. Factors like the personalities of others and varying cultural norms may play a role in what behaviours mean. Moreover, settings ranging in formality may dictate how individuals interact with one another, where formal environments may generate roles and norms which make it challenging to interpret others’ behaviours. Additionally, if behavioural cues are insufficiently expressive, their emotional content may be difficult to determine, subsequently influencing how well an observer can understand how another is feeling. Alternatively, if the observer incorrectly identifies the meaning of an action, it may be because they have not experienced an encounter like this before, or do not know what the behaviour represents within that person. For example, in some Asian countries including China, Korea, and Japan, it is considered improper to display negative emotions like anger and contempt in public, and instead a person may smile to maintain social congruity.[[176]](#footnote-177) Similarly, the presence of other behavioural cues and additional information may complicate an observer’s interpretations, leading them to draw incorrect conclusions. Therefore, causal factors for empathic inaccuracies or misunderstandings can be identified from a wide range of context variables, and as such, empathy with its successes and failures is best described by a perspective rooted in intersubjectivity generated from specific interactions. Consequently, *interaction theory* provides the best account for describing what empathy involves and how it emerges.

 Since the examination of the empathy literature involves a scientific discussion of *theory of mind* as a psychological capacity, we are able to draw more general conclusion regarding the minds of others. The perceptual ability to gain insight into another’s thoughts and feelings is evidently supported by common associative neuronal activity. These functional and behavioural similarities between individuals allows one to assume and even anticipate how others are likely to act, think, and feel in ways relatively comparable to our own experiences. We are able to understand aspects of the minds of others based on a perceptual capacity generated over early childhood. Additionally, by explaining theory of mind in terms of interactions arising between two or more people, we are able to feel somewhat confident in our understanding of others. Although this capacity is not infallible, it nonetheless provides a sufficient physiological foundation which enables communication and cooperation to occur between unique individuals. Moreover, we can conclude that joint attention establishes the necessary precondition for the learning of associations between expressions and their referents. At first, these associations relate to subjective feelings and their meanings or implications, and later in childhood, between words, symbols, or concepts and their definitions or referents. Therefore, from this examination of empathy and its empirical foundations, we are able to identify broader conclusions on how human minds are able acquire knowledge in general and develop an understanding of themselves, the minds of others, and the physical world. Thus, the “problem of other minds,” or how we can know the thoughts and feelings of another, is not quite the insurmountable dilemma as it was prior to the discovery of neural activity supporting this capacity.

 In conclusion, empathy involves a developed perceptual capacity which requires one to consider the subjective point of view of another. To accomplish this, individuals are required to suppress or regulate their own thoughts and feelings in order to adopt a new perspective. Failure to do so can result in an observer becoming distracted by their own feelings as an effect of adopting the perceived emotions of another person. It turns out that Lipps’s intuitions on empathy seem to accurately describe much of this process, where the discovery of neuronal processes activity has generated renewed interest in ideas first proposed by philosophical conjecture. Though our conception of this kind of neural activity has changed since its discovery, the term ‘mirror neuron’ remains as a label for the general behaviour of certain associative neurons.[[177]](#footnote-178) Given this, however, additional cognitive processing may still be required to fully understand the feelings or thoughts of another. Although the minds of others appear to be inaccessible at times, our evolutionary background has developed mechanisms for reducing this opacity, and for further reduction, we often appeal to our knowledge of others which is gathered and refined over the course of a lifetime. Though it seems *simulation theory* together with *theory theory* may fully explain empathy, Gallagher’s *interaction theory* offers a more robust explanatory approach as it specifies the role context plays in accurate or inaccurate interpretations of the feelings of others. Because acts of empathy occur within a particular situation between unique individuals, the nuance provided by *interaction theory* allows for an understanding of how and why this process succeeds or fails. The insight generated from this theory thus provides more information than *simulation* *theory* and *theory* *theory*, even when their virtues are combined into one theory. This is due to the second-person perspective *interaction theory* adopts, a perspective which best captures the process behind an act of empathy.

 Moreover, this theory is beneficial for considering the requirements we have placed upon social robots, as contextual factors significantly impact interpretations of human behaviour. It will be important for social robots to establish joint attention and reciprocity or turn-taking when communicating with humans for it to feel as if one were interacting with another human and not an artificial agent. To act with empathy, robots will need to correctly interpret the behaviours of people and the affective states behind behavioural cues, subsequently adopting these feelings in order to classify these acts as empathetic rather than sympathetic. For a robot to accomplish this, however, it must be able to appropriately represent human emotions in its own cognitive architecture. To best model the behaviours and capacities of humans, it must be able to leverage information provided within a particular social interaction to adjust its behaviours in an appropriate manner. The next chapter challenges this notion by providing a brief history of artificial intelligence and robotics to determine the current state of research and development, and whether this trajectory will one day produce robot empathy. The chapter concludes by arguing that even if robots were to mimic empathy-related behaviours, social robots are not capable of real empathy as it manifests in humans and some species of mammal. In virtue of their design, current robotic solutions are unable to adopt a human point of view because it is unable to understand the emotional cues and language of others, since it unable to experience emotional or affective states from its own lived perspective. Given the discrepancy between how information on affect manifests, empathy-like behaviour exhibited by social robots is merely an illusion.

Chapter 3 – The Limitations of Developmental Robotics

 This chapter outlines the history of artificial intelligence (AI) to provide context for the development of social robots as inspired by biological processes. Given the successful outcomes generated by neural network architectures, researchers have designed robots which replicate human development. One robot in particular named iCub is discussed in the second part of this chapter to demonstrate how sensorimotor learning scaffolds symbol grounding and language acquisition. While iCub appears to understand the referents of words, the final section argues that words related to emotions will remain ungrounded as a result of the robot’s body. Though embodied, iCub is not adequately modelled on human physiology and neurology to support an understanding of concepts related to affect.

3.1 – Progress in Artificial Intelligence

Though the term was coined in 1956, ‘artificial intelligence’ as a concept dates back to ancient Greece from Homer’s *The Iliad*.[[178]](#footnote-179) Philosophers since then, including Aristotle and Descartes, have discussed the possibility of behaviours arising from mechanical agents[[179]](#footnote-180). Similarly, the computer is an idea dating back to calculators crafted by Leibniz and Pascal and the analytic engine by Babbage.[[180]](#footnote-181) There is a long history to the philosophical concept of AI which will not be discussed here, as it is beyond the scope of our discussion of social robots. Instead, the start of our investigation into AI’s history will begin in the early to mid 20th century with the invention of the computer. From the beginning of the field of *artificial intelligence*, there were two approaches to designing sophisticated machines, consisting of symbolic reasoning and connectionism.[[181]](#footnote-182) While symbolic reasoning relies on explicit instructions and concepts, connectionistic approaches use artificial neural networks to identify patterns from repeated instances of data processing. Subsequent progress in AI has been described in terms of cycles consisting of “winters” and “springs” or “Golden Ages” which are characterized by stops and starts in research and development.[[182]](#footnote-183) Though many have remained optimistic about AI development and its potential capacities, my aim is to demonstrate significant limitations in our attempts at replicating human intelligence. To accomplish this, a brief historical account of AI is required. During the 1950’s and 1960’s, the dominant approach to building AIs involved symbolic reasoning, however, in the 1980’s, a renewed interest in neural networks shifted research and development in AI towards connectionism. By the early 1990’s, a growing interest in robotics and *embodiment* aimed to ground meaning by replicating human learning. Robots designed to learn about the world from experience are theoretically able to subsequently learn how these elements are represented in symbols and language. As AI developed over history, a trend toward the modelling of biological systems to generate intelligent behaviour emerged, where *embodiment* introduced a phenomenological perspective to further develop learning.

 The precursors to the idea of “artificial intelligence” can be identified in a number of technological developments in the 1930’s and 1940’s. In 1936, Alan Turing created the Turing Machine, a theoretical machine capable of performing calculations based on a set of rules by reading and writing information to a tape of infinite length.[[183]](#footnote-184) That same year, the first programmable computer was created by the German engineer Konrad Zuse.[[184]](#footnote-185) His machine performed calculations using binary numbers by reading instructions from a punched tape, controlled by a computing unit and capable of storing information.[[185]](#footnote-186) Six years later, Isaac Asimov published *Runaround* with its “Three Laws of Robotics” in 1942, stipulating that robots must not harm humans, nor allow them to be harmed, along with protecting its own existence provided it does not conflict with the previous laws.[[186]](#footnote-187) The following year, the first mathematical model of the biological neuron was presented by Warren McCulloch and Walter Pitts,[[187]](#footnote-188) demonstrating an all-or-nothing firing pattern which can then be used to generate logical operations.[[188]](#footnote-189) In 1945, John von Neumann released a report on a computer system called EDVAC, originally developed by Presper Eckert and John Mauchly at the Moore School of Electrical Engineering at the University of Pennsylvania.[[189]](#footnote-190) Despite being created by Eckert and Mauchly, von Neumann would later receive credit for the computer’s invention, as his was the only name listed on the report detailing EDVAC’s functionality.[[190]](#footnote-191) The so-called “von Neumann architecture” is still used in computers today,[[191]](#footnote-192) consisting of a control unit, an arithmetic/logic unit, a memory unit, as well as input and output devices such as a keyboard and screen.[[192]](#footnote-193)

 During this period of time, computers were very large and expensive, often referred to as “giant brains.”[[193]](#footnote-194) Their use of vacuum tubes rather than transistors and microprocessors, as these would not be invented until later that century, meant these machines were much bigger and costlier than modern personal computers.[[194]](#footnote-195) In 1948, the mathematician Norbert Wiener’s book *Cybernetics: Or Control and Communication in the Animal and the Machine* launched the “cybernetics movement” with Warren McCulloch, Walter Pitts, and John Von Neuman.[[195]](#footnote-196) The 1949 publication *Giant Brains: Or Machines That Think* by computer scientist Edmund Berkeley compares machines to human brains by describing them as “hardware and wire instead of flesh and nerves”[[196]](#footnote-197) and because they could process information similarly to a brain, “a machine, therefore, can think.”[[197]](#footnote-198) In 1950, Alan Turing’s paper *Computing Machinery and Intelligence* asked whether computers think, responding by stating that a computer can be considered to think if it can pass the “Imitation Game.”[[198]](#footnote-199) The same year, Claude Shannon, the father of information theory, published *Programming a Computer for Playing Chess*,[[199]](#footnote-200) and Marvin Minsky created the first neural network of a rat running a maze.[[200]](#footnote-201) Although interest in thinking machines was increasing, the term “artificial intelligence” would not be created for another four years.

 A series of conferences would lead to the creation of the term and field of *artificial intelligence*. In 1948, the conference *Hixon Symposium on Cerebral Mechanisms in Behaviour* held in Pasadena, California, featured papers by Warren McCulloch, John von Neumann, and psychologist Karl Lashley whose presentation would lay the foundation for cognitive science.[[201]](#footnote-202) These presentations investigated how the nervous system and brain compares to computer systems,[[202]](#footnote-203) and in attendance was computer scientist John McCarthy,[[203]](#footnote-204) who would coin the term *artificial intelligence* eight years later. The 1955 conference *Session on Machine Learning* held in Los Angeles, California, featured papers on neural networks by Belmont Farley and Wesley Clark, computational image processing by Gerald Dinneen and Oliver Selfridge, and a program for playing chess presented by Allen Newell.[[204]](#footnote-205) The following year, John McCarthy would include the term *artificial intelligence* in a proposal written for the *Dartmouth Summer Research Project*, a workshop held in Hanover, New Hampshire.[[205]](#footnote-206) The proposal for funding described a study to be conducted of simulating learning and intelligence in machines, with coauthors including Nathaniel Rochester, Marvin Minsky, and Claude Shannon.[[206]](#footnote-207) The proposed “study” became a workshop which, in addition to the proposal’s authors, included Arthur Samuel, Oliver Selfridge, Allen Newell, Herbert Simon and Cliff Shaw.[[207]](#footnote-208) Here, Newell, Simon, and Shaw presented the Logic Theorist program capable of proving 38 of 52 theorems from Whitehead and Russell’s *Principia Mathematica*.[[208]](#footnote-209) In 1958, the conference *Mechanisation of Thought Processes* was held in Teddington, Middlesex, England, and featured papers by Minsky, McCarthy, Selfridge, and McCulloch.[[209]](#footnote-210) Here, Selfridge presented a paper on symbol-manipulation for pattern recognition and McCulloch presented a paper on neural network signal switching.[[210]](#footnote-211) These conferences would stir up global interest in the idea of developing systems capable of replicating or surpassing human mental abilities.[[211]](#footnote-212)

 From the outset, two approaches to AI architecture emerged: *symbolic reasoning* and *connectionism*. In the beginning, the dominant approach was symbolic AI, especially heuristic search and knowledge representation.[[212]](#footnote-213) Heuristic search involves the use of a general rule to guide the system toward producing a solution despite not guaranteeing a solution, such as “protecting the queen” in a game of chess.[[213]](#footnote-214) To avoid becoming mired by irrelevant solutions from the use of heuristics, researchers developed programs which aimed at representing human knowledge to assist with producing outputs. Data structures used by the system would reflect or replicate human knowledge and algorithms would use these representations to perform inferences to produce an output.[[214]](#footnote-215) Notable examples include McCarthy’s Advice Taker which, given a set of propositions about the world, would deduce conclusions about actions to be performed.[[215]](#footnote-216) Similarly, the General Problem Solver created by Newell, Simon, and Shaw in 1957, leveraged heuristics from the Logic Theorist to generate a system capable of breaking problems down into sub-problems.[[216]](#footnote-217) From there, each sub-problem could be represented symbolically and compared to the representations stored in the system, where the difference between these representations indicated an operation to minimize this difference.[[217]](#footnote-218) Alternatively, researchers like McCulloch and Selfridge were interested in replicating neural networks to mimic how the brain works.[[218]](#footnote-219) In 1958, Frank Rosenblatt introduced the *perceptron*, a single-layer neural network based on the mathematical model created by McCulloch and Pitts in 1943.[[219]](#footnote-220) In a neural network, a representation is generated from the activated patterns of neurons, where processing is achieved by propagating these activations to the nodes of the network through their interconnections. This propagation is governed by *weights* or numerical values between pairs of nodes, where learning occurs through the change of the value of these weights based on the accuracy of the output.[[220]](#footnote-221) Rather than using human-based knowledge and representations, neural networks are sub-symbolic and can learn rapidly about incoming information by updating how neurons in the network fire.[[221]](#footnote-222) While the two main branches of AI research, namely the symbolic and connectionist approaches, view problems quite differently, both are still used today and have even been combined to create hybrid systems.[[222]](#footnote-223)

 The mid 1950’s through to the early 1970’s is characterized as the “First Golden Age” of AI given the successes of early programs and systems to perform sophisticated tasks.[[223]](#footnote-224) With large sums of funding sourced from private companies and governmental agencies in the United States like the Defence Department’s Advanced Research Projects Agency, subsequently known as DARPA.[[224]](#footnote-225) Contributions provided by individuals from the Massachusetts Institute of Technology (MIT), Carnegie Mellon University, and Stanford assisted to the flourishing of AI over this period of time.[[225]](#footnote-226) In 1958, Minsky and McCarthy established the Artificial Intelligence Laboratory at MIT, where McCarthy would create the programming language LISP.[[226]](#footnote-227) Improvements in computing hardware would also contribute to AI research, as increases in processing speeds and memory capacity improved efficiency.[[227]](#footnote-228) Early projects in robotics began during this period as well,[[228]](#footnote-229) with work on the Stanford Cart project beginning in 1960. This remote-controlled robot was operated by a computer using television camera signals and was able to navigate around obstacles.[[229]](#footnote-230) In 1961, General Motors introduced the Unimate robot to its factories to unload car parts from die-casting machines capable of operating under high-temperatures.[[230]](#footnote-231) Development of the first mobile robot for performing tasks began in 1966, named Shakey from its tendency to wobble when coming to an abrupt stop.[[231]](#footnote-232) The first chatbots emerged during this period as well, as i**n 1965, the chat program ELIZA by** Joseph Weizenbaum is introduced, capturing the imaginations of its users to the surprise of its developers.[[232]](#footnote-233) Modelled on Rogerian psychotherapy, the inquisitive nature of ELIZA generated in its users a sense of interpersonal connection as a consequence of its style of questioning.[[233]](#footnote-234) Because the system did not understand the words it was using when responding to human input, it would ask users to clarify ideas or concepts as a way of overcoming limitations in interpretation and production.[[234]](#footnote-235) As such, ELIZA generated an illusion of knowledge and understanding from the user’s background assumptions and inferences from the interpretation of its output messages.[[235]](#footnote-236) ELIZA would become famous for its ability to engage users; however, this accomplishment was more a product of human psychology rather than technical achievement.[[236]](#footnote-237)

 The abundance of innovation and excitement generated a lot of optimism during this time.[[237]](#footnote-238) In 1957, Herbert Simon predicted AI would beat a world champion at chess in the next 10 years.[[238]](#footnote-239) In actuality, it would not be until 1997, 4 decades later, when World Champion and Grandmaster Gary Kasparov was defeated by Deep Blue.[[239]](#footnote-240) In 1967, Marvin Minsky stated that “Within a generation... the problems of creating ‘artificial intelligence’ will be substantially solved.”[[240]](#footnote-241) Although much progress has been made since then, this prediction has yet to be realized.

 Enthusiasm dwindled as expectations could not be fulfilled, and the *First AI Winter* would arrive in 1969 when Marvin Minsky and Seymour Papert published their book *Perceptrons* which demonstratedthe limitations of Rosenblatt’s single-layer neural network.[[241]](#footnote-242) One limitation included the *exclusive-or problem*, where the neural network could not recognize an entity which contains one of two properties but not both.[[242]](#footnote-243) It was concluded that neural networks were not a promising direction for research, and as a result, funding for researching AI in general would cease for about a decade.[[243]](#footnote-244) Furthermore, in 1972, Hubert Dreyfus published *What Computers Can’t Do* which criticized the prospect of symbolic AI to replicate some forms of human reasoning, such as intuition.[[244]](#footnote-245) Additional criticism against symbolic AI emerged in 1973 in a report by Prof. Sir James Lighthill which stated that while impressive, research outcomes had failed to live up to early optimistic expectations.[[245]](#footnote-246) This report suggested that the largest issue with expert systems was their failure to acknowledge the *combinatorial explosion* of symbolic approaches, where the act of programming the required concepts or knowledge generates a quantity of code which cannot be supported by existing hardware.[[246]](#footnote-247) Moreover, DARPA’s Speech Understanding Research project had not seen the successes researchers had hoped for,[[247]](#footnote-248) causing the agency to cut funding for this project in 1974.[[248]](#footnote-249) Together, these criticisms and obstacles negatively impacted public support and funding for AI projects, causing research to stall until the 1980s.

 While AI in the United States was witnessing a stagnation, organizations around the world were still working on different AI systems and making progress.[[249]](#footnote-250) In 1972, Teuvo Kohonen at the Helsinki University of Technology in Finland published *Correlation Matrix Memories*[[250]](#footnote-251) and would continue to develop approaches to building neural networks throughout the decade before focusing on *self-organizing maps* (SOMs) in the 1980’s.[[251]](#footnote-252) **The year 1972 also witnessed** the first anthropomorphic robot, named WABOT-1, completed in Japan at Waseda University, where it could walk, carry objects, and communicate with humans.[[252]](#footnote-253) Work on self-organizing neural networks would continue to be pursued by Christoph von der Malsburg in Germany,[[253]](#footnote-254) and in 1973, he would publish the article *Self-Organization of Orientation Sensitive Cells in the Striate Cortex.*[[254]](#footnote-255)Inspired by Hubel and Wiesel’s discovery of neuronal sensitivity to specific line orientations in the cortices of higher vertebrates, this work presented a method for training neural networks where single neurons become capable of responding to specific orientations of line segments, such as vertical or horizontal lines.[[255]](#footnote-256)In 1975, Japanese researcher Kunihiko Fukushima created a multi-layered neural network called Cognitron which was capable of self-organizing without the need for feedback or supervision.[[256]](#footnote-257) So although AI research and development seemed to stagnate during the 1970’s in the United States, researchers elsewhere continued to contribute to the growing body of research.

Renewed interest in AI research began in 1980 and spirits remained high for the next 7 years. The period of time known as the *Second Golden Age* was characterized by advances in the design of neural networks.[[257]](#footnote-258) John Hopfield created a new type of learning neural network in 1982, one which recurrently passes information repeatedly through the same network node for further refining.[[258]](#footnote-259) Geoffrey Hinton and Terry Sejnowski published a paper on a learning algorithm for multi-layered neural networks in 1985,[[259]](#footnote-260) and David Rumelhart and James McClelland published *Parallel Distributing Processing* in 1986.[[260]](#footnote-261) The latter presented a method for overcoming the *exclusive-or problem* identified decades prior, where multi-layered neural networks are trained by the technique called *back propagation*.[[261]](#footnote-262) There were also large successful projects in symbolic AI during this period, with expert systems created for locating molybdenum mineral ore deposits, forecasting thunderstorms, and identifying points of trouble in telephone networks and recommending corrective measures.[[262]](#footnote-263) The Japanese government also contributed to this Second Golden Age by launching theFifth Generation computer project which aimed to generate humanlike communication and reasoning.[[263]](#footnote-264)

 By this point, three main approaches to machine learning could be identified: supervised, unsupervised, and reinforcement learning.[[264]](#footnote-265) All of these approaches are modelled on *associative* *learning*, where a connection between two stimuli is established when presented in short succession. Associative learning will be discussed in further detail in the next chapter; however, introducing this idea here provides further background for the functionality of neural networks. In associative learning, neurons which “fire together, wire together”[[265]](#footnote-266) to establish an association between two stimuli, such as an image and a word. In supervised learning, the association generated relies on feedback regarding the correct answer or the degree of error between the program’s output and the ideal or goal state, altering the functionality in response.[[266]](#footnote-267) Without this feedback, unsupervised learning uncovers commonalities or structures from incoming data based on intrinsic features and patterns.[[267]](#footnote-268) Feedback can also be provided through the use of rewards, and reinforcement learning is an approach to machine learning which provides a reward in response to correct actions taken, thus increasing the likelihood this action occurs in the future.[[268]](#footnote-269) While supervised learning mirrors human pedagogy,[[269]](#footnote-270) unsupervised learning reflects the functioning of perceptual capacities in humans and animals,[[270]](#footnote-271) and reinforcement learning simulates behaviour training in a wide range of animals.[[271]](#footnote-272) From neural networks to learning paradigms, approaches to artificial intelligence modelling biological processes illustrate promising directions for generating a range of key capacities and behaviours.

The *Second AI Winter* occurred from 1987 to 1993.[[272]](#footnote-273) In 1987, there was a collapse of the market for specialized AI computer hardware.[[273]](#footnote-274) Desktop computers were catching up with these specialized machines and as such, were no longer in demand. Moreover, a few revelations about expert systems like XCON, which was created to much acclaim during the previous *Golden Age*,[[274]](#footnote-275) demonstrated these systems were expensive to maintain, difficult to update, unable to learn, and prone to mistakes.[[275]](#footnote-276) Additionally, results from Japan’s Fifth Generation project had been underwhelming as expectations were higher than what had actually been achieved.[[276]](#footnote-277) As a result, funding was once again withdrawn by governmental agencies in the United States and Japan.[[277]](#footnote-278) It was during this winter, in 1988, that Hans Moravec introduced his paradox: he noted that some problems are easy for computers and difficult for humans, like proving theorems, while others appear to be rather difficult for AIs but easy for humans, like recognizing a face.[[278]](#footnote-279) Arguably, this fact arises from the physical and functional differences between animals and computers, a topic which will be explored further in subsequent chapters.

 Despite these setbacks, this period marked the beginning of the application of embodied cognition to computers and AIs. Some early proposals, which could interact with their environments were suggested in the mid to late 1980s,[[279]](#footnote-280) as had been originally suggested in the cybernetics movement of the 1940’s.[[280]](#footnote-281) Robotics introduced a new approach to AI because behaviour could emerge from learning generated by neural networks.[[281]](#footnote-282) Robots that can navigate the environment and interact with its features can build up knowledge and reasoning from experience interacting with the world.[[282]](#footnote-283) The focus shifted from building computer programs as components of intelligence to building agents which generate knowledge and intelligence from experience.[[283]](#footnote-284) In 1990, Rodney Brooks published the article *Elephants Don’t Play Chess* which argues that symbolic AI is “fundamentally flawed” given the symbols it uses are “ungrounded representations.”[[284]](#footnote-285) While these symbols aim to represent entities in the world, their meaning is unknown by the system and only the human user is capable of connecting the symbols to their meaning.[[285]](#footnote-286) Moreover, symbolic systems work with discrete concepts and relations, generating an inflexibility or rigidity to the system itself.[[286]](#footnote-287) Instead, Brooks proposed intelligent systems ought to be *embodied*, or robotic, to ground these symbols or representations on environmental information captured by sensors.[[287]](#footnote-288) The benefit to this approach is that agents would be able to react to dynamic, noisy environments by having smaller subsystems generate simple behaviours, where complex behaviour emerges from the interaction of these underlying components.[[288]](#footnote-289) By creating autonomous entities, learning occurs by interacting with the world and generating learned associations from experience rather than being programmed into the system directly.[[289]](#footnote-290) Although Brooks was on the right track with respect to producing responsive and context-sensitive behaviours, embodiment is insufficient for symbol-grounding, an idea which will be explained further in this chapter and in subsequent chapters.

 This new approach to AI brought about the *Third Golden Age* in the early 1990’s which continues to this day.[[290]](#footnote-291) In 1993, Rodney Brooks began work on Cog the Humanoid Robot with a team of researchers and graduate students which included Cynthia Breazeal,[[291]](#footnote-292) who would later become the Dean of Digital Learning at MIT.[[292]](#footnote-293) Cog is a torso bolted to a bench with arms and a head capable of machine-vision.[[293]](#footnote-294) As previously stated, **1997 witnessed the defeat of** the world champion chess player Gary Kasparov in a match against Deep Blue, a symbolic AI system developed by IBM.[[294]](#footnote-295) Two years later, the robotic dog AIBO by Sony was introduced to the public after years of development in Japan,[[295]](#footnote-296) and in **2000,** Kismet, a robot that could recognize and simulate facial expressions and emotions, was created by Cynthia Breazeal.[[296]](#footnote-297) Despite appearing to represent emotional states, Kismet’s expressions were superficial and unaccompanied by any underlying experiences or changes to its internal motivations, unlike humans and animals. As discussed in depth in a later section of this chapter, emotional expressions reflect internal, affective states which are subjectively experienced by the individual exhibiting them, often in response to particular stimuli or circumstances.

 The year 2000 was also the launch of *developmental* *robotics*, an approach to symbol-grounding based on a model of human learning in childhood.[[297]](#footnote-298) By modelling the stages of childhood development, researchers can create architectures which generate increasingly sophisticated behaviours with practice.[[298]](#footnote-299) The emerging behaviours which manifest are the result of interactions with its environment,[[299]](#footnote-300) incorporating new information about its features and objects, rather than having these aspects programmed within the robot’s code.[[300]](#footnote-301) Instead, these robots use incoming sensory data to learn about objects, actions, and environmental features to generate appropriate responses over time through experience.[[301]](#footnote-302) By combining and refining simple actions and mechanisms, larger and more complex abilities and functionality can emerge over time, as capacities are generated from repeated experiences.[[302]](#footnote-303) Learning the names of objects provides knowledge of the world for the robot, where this knowledge may be used in the generation of linguistic expressions and verbal communication.[[303]](#footnote-304) By following a model of human development, a potential solution to the symbol-grounding problem had been identified, further corroborating that biological models provide a promising direction for generating solutions to problems within AI.

 **AI has since exploded in its ability to perform a number of sophisticated tasks, especially thanks to *Big Data*,**[[304]](#footnote-305) **a phenomenon which roughly includes the collection, processing, and sharing of data generated by users of devices and services.**[[305]](#footnote-306) **Also contributing to the rise of neural networks were further improvements in computing hardware and the construction of global internet infrastructure.**[[306]](#footnote-307) **Moreover, language generation continued to improve, launching new consumer devices to execute tasks through voice commands. In 2010, Apple released Siri, a virtual assistant on iOS, adapting to create unique profiles to individualize the experience.**[[307]](#footnote-308) **The following year, the natural language system Watson created by IBM defeated two former** Jeopardy! **champions Ken Jennings and Brad Rutter.**[[308]](#footnote-309) **The first social robot for families named Jibo, developed by Cynthia Breazeal, launched in 2014 and was intended to serve as a personal assistant for the home, capable of tasks such as placing phone calls, set reminders, and take photos.**[[309]](#footnote-310) **This was also the year Google acquired the company DeepMind with its neural network system which learns to play games through trial and error only.**[[310]](#footnote-311) **In 2016, a DeepMind system named AlphaGo beat world champion Go player Lee Sedol,**[[311]](#footnote-312) **further demonstrating the power of deep neural networks for learning.** Today, ChatGPT has been responsible for producing much excitement around *large language models* (LLM) as it provides detailed responses to questions asked by users.[[312]](#footnote-313) In 2023, Bing released their text-to-image generation system, producing detailed renderings incorporating the elements specified by user input.[[313]](#footnote-314) Text-to-video generation would follow about a year later with the introduction of a model called Sora by OpenAI, the creator of ChatGPT.[[314]](#footnote-315) Thus, AI seems on track to continue meeting and potentially exceeding human ability in some ways, however, the question remains about whether it will meet our expectations with respect to complex social interaction and empathy.

 By investigating the history of artificial intelligence, it becomes apparent that programs inspired by cognition and biological processes running on digital computers have become the dominant approach to recreating human intelligence. As scientific progress and technological development expanded over the 20th century, our approaches to AI and software development increasingly turned to biology for inspiration. Neural networks, especially when paired with large datasets, became increasingly capable of generating impressive results, proposing a new approach to recreating human behaviour. Moreover, when a neural network is embodied in a robot, it can learn about the world in a manner which is similar to human development. The successes produced by this approach to AI continued to reinforce the idea that modelling biological processes can generate fruitful results, as it became increasingly apparent that the body and exterior environment influence cognition and behaviour. The following section examines particular outcomes from an industry-leading robot[[315]](#footnote-316) named iCub to demonstrate the current abilities of developmental robots.

3.2 – Introducing iCub

This section explores a particular developmental robot named iCub to demonstrate a specific implementation of a model of human development. A description of its architecture is provided to give context to its abilities, illustrating how behaviours result from computer code. Currently, iCub is able to learn the names of objects and converse with humans. Examining iCub provides insight into the current status of robot development with some ability to predict how these machines might develop during the next few years and into the future. Although it may seem like iCub has an understanding of the world, I ultimately argue that there is no genuine perspective in this machine. The discussion of its functionality presented here provides the explanatory foundation for the argument presented in the next section; specifically, why iCub cannot adopt a human perspective.

 iCub is the result of a collaborative research initiative called RobotCub, funded by the European Commission beginning in 2004 to create an embedded cognitive system with artificial intelligence.[[316]](#footnote-317) Created by Giulio Sandini, Giorgio Metta, and David Vernon, this humanoid robotic platform for researching embodied cognition consists of open-source hardware and software, allowing others to build upon existing frameworks to contribute to the development of iCub.[[317]](#footnote-318) Modelled after a three year old child, iCub stands at 104cm and weights 22kg with 53 *degrees of freedom* (DOF), most of which are located in the upper body.[[318]](#footnote-319) Its hands have been carefully designed, with 9 DOF, independent thumbs, index, and middle fingers, and fully driven by tendons to operate like a human hand.[[319]](#footnote-320) Moreover, the fingertips, palm, and forearm contain pressure sensors.[[320]](#footnote-321) The reason is because humans learn about the world through the manipulation, interaction, and feedback of objects in an environment, making this a necessary aspect of iCub’s functionality.[[321]](#footnote-322) The robot contains two digital cameras for binocular vision, microphones for auditory processing, gyroscopes for detecting orientation, accelerometers for measuring the rate of change of velocity, and torque sensors collecting force data used for governing motor signals.[[322]](#footnote-323) The main computational unit is located in the head,[[323]](#footnote-324) however, further processing of iCub’s sensorimotor data is processed externally in a separate computer,[[324]](#footnote-325) where this information can be transmitted wirelessly or through an Ethernet cable.[[325]](#footnote-326)

 The iCub architecture consists of 3 layers: hardware, firmware, and software, where the firmware serves as a functional bridge between the hardware and the software.[[326]](#footnote-327) Data produced by hardware sensors must be preprocessed before being used by the software, and as such, relies on firmware for proper formatting. The firmware often used in iCub is called YARP which stands for Yet Another Robotic Platform. However, iCub can run on other middleware architectures as well, such as the Robot Operating System (ROS) and OROCOS or Open Robot Control Software.[[327]](#footnote-328) YARP runs on dedicated CPUs throughout the body, processing sensorimotor data where communication between boards uses protocols.[[328]](#footnote-329) It achieves this through *ports* which are assigned with names such as “camera/right” to access information produced by hardware.[[329]](#footnote-330) These ports can send and receive data to any other port, and connections between ports are easily added or removed, using a variety of different protocols or transports.[[330]](#footnote-331) Together, they create an inter-communicative network where data from sensors can be accessed throughout the network.[[331]](#footnote-332) Moreover, the internal state of iCub can be viewed by software on the external machine to assist developers with troubleshooting and testing.[[332]](#footnote-333) These software systems use libraries of computer code which provide instructions for iCub to perform behaviours. One example is the iCub-HRI library which supports perception, object manipulation, social interaction, including face and action recognition, babbling, and learning the names of objects.[[333]](#footnote-334)

 The cognitive abilities of iCub are generated from sensorimotor mapping and coordination from basic reflexes which serve as the foundation for learning more complex behaviours.[[334]](#footnote-335) It first learns to improve control and coordination of its eyes and neck by attending to objects or features of the environment.[[335]](#footnote-336) With further development, iCub gains better control over movement in its shoulders, elbows, and torso, generating representations of its own body. It learns to crawl before standing and walking,[[336]](#footnote-337) and with its hands free to reach for objects, iCub’s manual dexterity will continue to improve.[[337]](#footnote-338) Similarly to human children, this also facilitates object manipulation as the robot can pick up and inspect objects. As its ability to grasp and handle objects improves, iCub builds up other abilities like object recognition and word learning.[[338]](#footnote-339) By interacting with humans, iCub can learn the names of objects and features of the world, following the gaze of others to attend to specific items or stimuli.[[339]](#footnote-340) By using internal models of its body, iCub is eventually able to navigate its environment to learn more about its features and dynamics, both physical and social.[[340]](#footnote-341) This “ontogenetic training program” follows human development as skill acquisition and improvement enables the robot to build up more complex behaviours by mastering and combining simple actions.[[341]](#footnote-342)

 This improved control and dexterity allows iCub to learn object *affordances* which are “action possibilities” for a given item, like grasping the handle of a mug.[[342]](#footnote-343) The theory of affordances was first introduced by psychologist James J. Gibson and suggests a “complementarity of the animal and environment” given the interaction between the individual’s body and elements of the physical world.[[343]](#footnote-344) The environment offers or *affords* actions which can be performed as a result of the body’s morphology. As such, it suggests that humans and animals have a perceptual ability which can identify the utility or purpose of an item or environmental feature given its specific physical composition.[[344]](#footnote-345) iCub learns affordances using Bayesean networks as a model of the discrepancies between actions, objects, and their effects based on information from sensors in the hands and eyes.[[345]](#footnote-346) From these variables and discrepancies, it is able to learn the relations between actions, objects, and effects where these relationships are updated as iCub continues to gain experience. Just like human children, iCub learns how to use tools and interact with objects by investigating their features through play and experimentation.[[346]](#footnote-347)

 It is through these interactions that iCub is thought to ground language on sensorimotor information by creating associations between spoken language and objects.[[347]](#footnote-348) As a separate research project, also funded by the European Commission, the iTalk Project aims to create a cognitive platform to support language learning for the iCub robot.[[348]](#footnote-349) By combining auditory signals from speech with visual information, iCub creates an inner representation which it uses to determine which objects are being referred to in order to reach for the ascribed objects in the environment, guided by feedback from its hands to better direct its movement.[[349]](#footnote-350) Similarly, the Epigenetic Robotics Architecture (ERA) can also generate word learning using self-organizing maps (SOMs) trained to recognize features, body position, and speech data, where associations between mapped representations follow from the frequency of the association.[[350]](#footnote-351) The SOMs are first trained to recognize objects and their features before learning to represent more complex objects and relations.[[351]](#footnote-352)

 A framework for emotions has also been developed, allowing iCub to mimic expressions detected from scanning human faces, where positive reinforcement from humans functions as a reward for a SOM to learn whether its identification is correct.[[352]](#footnote-353) iCub can recognize and imitate seven “universal” emotions: anger, disgust, sadness, fear, surprise, happiness, in addition to a neutral face. Furthermore, an architecture of emotion has been developed which allows iCub to tailor its behaviour to reflect the detected mood or personality of the individual its interacting with, based on how engaged they are with the robot.[[353]](#footnote-354) If iCub detects a person uninterested in interacting, it will continue to look down and play with its toys, however, if individuals take an interest in iCub, it will make eye contact, direct its gaze at its toys, and point to them, encouraging the participant to interact.[[354]](#footnote-355) This architecture also allows for emotion recognition and mimicry, choosing actions which are predicted to increase the human participant’s happiness during interactions.[[355]](#footnote-356)

 iCub can also learn to count to ten using its fingers. An experiment by Di Nuovo et al. demonstrates an ability for iCub to map auditory information of spoken numbers to its hands, moving the appropriate finger joints in response to the numbers one through ten when spoken in sequence.[[356]](#footnote-357) As is the case with human children, finger counting aims to assist in the development of internal representations of numbers, establishing a foundation for developing a broader understanding of mathematical concepts in future research.[[357]](#footnote-358)

 This glimpse at iCub and its capacities indicates that AI embodiment appears to be a promising line of research for developing agents capable of socializing with humans. It seems plausible that with more research and development, iCub and similar robots will one day be able to interact and communicate with others in a humanlike manner. Because iCub is able to learn to recognize and respond appropriately to words for items in its environment, it appears this ability to learn from practice and experience is sufficient for establishing the meanings of words. In the following section, an examination of emotions and affective states demonstrates why this is not the case.

3.3 – iCub’s Failure to Empathize

The goal to be met by iCub and developmental robotics in general is a solution to the *symbol-grounding* *problem* which seeks to explain how meanings or referents become associated to words and concepts used by humans. A response proposed to this problem was presented by Stevan Harnad in his paper ‘Other Bodies, Other Minds: A Machine Incarnation of an Old Philosophical Problem’ where he expands upon Alan Turing’s ImitationGame*.* Harnad recommends that instead of testing AI intelligence through conversing using text-based chat, AI should be embodied in a robot, such that they can “recognize and identify and manipulate and describe real objects, events and states of affairs in the world.”[[358]](#footnote-359) Harnad calls this modified intelligence test the *Total Turing Test* (TTT) explaining that “the candidate must be able to do, in the real world of objects and people, *everything* that real people do, in a way that is indistinguishable (to a person) from the way real people do it.”[[359]](#footnote-360) By building AI systems with integrated sensorimotor functionality, the meanings of words can be learned from bottom-up functionality as the agent engages with its environment.[[360]](#footnote-361) Harnad recommends this should be implemented in a *“*non-symbolic” manner,[[361]](#footnote-362) one which does not follow the approach called *symbolic reasoning* which was common in early AI research, as discussed in the first section of this chapter. Alternatively, robotic systems should detect sensory features and elements within the environment from a bottom-up approach, similar to the way neural networks operate today. This way, these features and elements can be combined and associated together to create internal structures which grounds the meanings of words. This understanding would be used to support language comprehension and production, allowing the robot to recognize which object or feature is being referred to. Thus, according to Harnad, an AI which passes the TTT will act sufficiently humanlike and as a result, will be treated as if it has a mind of its own. Specifically, “if our only basis for judging that other people have minds is that they behave indistinguishably from ourselves, then there’s no ground for withholding the same benefit of the doubt from robots.”[[362]](#footnote-363)

 From the previous section’s exploration of iCub and its current abilities, sensory projections created from neural networks organize incoming information from the external environment, generating internal abstract representations derived from stimuli. Further, iCub learns about objects by “playing” with them and as a result, is able to associate the object with a word. This extends to emotions as well, as iCub can identify the expression of basic emotional states in humans. Though this information influences iCub’s behaviour, the robot does not feel nor experience the emotional information its body uses to generate behaviours. As will be discussed shortly, *experiences* of emotions and affective states are required to ground the meanings of words and concepts related to emotions. Since iCub lacks this ability, the grounding of emotions in this manner is insufficient.

 As mentioned previously, iCub can learn to recognize human emotions like happiness, sadness, anger, among others, based on the movement of muscles in the face. These categories of affect have been described as *basic* *emotions* by the psychologist Paul Ekman from his study of facial expressions in the 1960’s and onward.[[363]](#footnote-364) Building on Darwin’s theory of emotion in *The Expression of the Emotions in Man and Animals*, his theory was formed around the measurement of behavioural cues, particularly facial expressions, which are consistently or universally associated with emotions.[[364]](#footnote-365) Particular movements of facial muscles are associated with emotions, and these can be grouped into six “basic” emotions: happiness, sadness, fear, anger, disgust, and surprise.[[365]](#footnote-366) Moreover, basic emotions are associated with nine specific characteristics.[[366]](#footnote-367) The first characteristic is that basic emotions exhibit distinctive universal signals, involving a set of configurations of facial muscle movements. Though similarities will exist between individuals, differences have also been observed. Anger, Ekman notes, can involve more than sixty particular expressions depending on the situation and causal factors, where subtle differences may involve the lips tightly pressed together or slightly open and “in a square shape.”[[367]](#footnote-368) These variations within categories of emotion are due to an array of influences, including individual physiological differences, previous experiences, and cultural norms.[[368]](#footnote-369) As such, the boundaries between groups or categories can be blurry and ill-defined, however, exist nonetheless.[[369]](#footnote-370) Other characteristics of basic emotions listed by Ekman include their existence in other primates besides humans, and consisting of particular physiological changes within the body.

 Ekman appeals to changes in the *autonomic nervous system*, responsible for bodily functions such as heart rate and breathing, to demonstrate the adaptive qualities of emotions, and thus their universal qualities.[[370]](#footnote-371) It has been suggested that these automatic responses serve an adaptive purpose which is not limited to humans. For example, a facial expression indicating disgust suggests to conspecifics to avoid eating a particular item,[[371]](#footnote-372) while fearful expressions indicate the presence of a threat to be considered by others. Moreover, basic emotions can be reliably initiated by certain events or stimuli, resulting in emotions which are shared by most individuals.[[372]](#footnote-373) The loss of a loved one, for example, regularly invokes sadness in the majority of individuals from a number of cultural backgrounds. Furthermore, basic emotions are characterized by a quick onset and a brief duration, involving an automatic appraisal of the stimulus or situation which is not intentionally induced by the individual. Basic emotions also indicate a “coherence among emotional response,” where changes in facial expressions are usually accompanied by physiological changes.[[373]](#footnote-374) Finally, basic emotions involve an “unbidden occurrence” which, as the result of automatic, physiological changes and a rapid onset, happen *to* an individual rather than being chosen *by* them. Ekman succinctly states “One cannot simply elect when to have which emotion.”[[374]](#footnote-375) Thus, basic emotions involve a number of universal characteristics, and while these characteristics involve a degree of variation, are said to be present in all humans, regardless of how affective states are subsequently expressed or regulated.

 Basic Emotion Theory (BET) considers emotions to be *natural kinds* where members of a category of emotion share one or more common features, namely a unique pattern of specific outputs in the form of behaviours.[[375]](#footnote-376) These categories are thought to exist ontologically, external to human minds and out in the world waiting to be discovered.[[376]](#footnote-377) Prior to Darwin’s theory of natural selection, categories of emotions were considered to be akin to Platonic types, or ontologically-independent aspects of psychological functioningwhich gives rise to behaviours once instantiated within particular individuals*.*[[377]](#footnote-378) Distinguished by signatures in the body, each emotion’s physical *essence* is the way it generates changes in the peripheral nervous system, facial muscles, or the structure or function in the mammalian brain. As causal agents, basic emotions have been selected for by evolutionary processes, motivating individuals to behave in adaptive ways as indicated by stimuli detected in the environment, stemming directly from the detection of a stimulus.[[378]](#footnote-379) As such, they *cause* individuals to act in certain ways, and because of their adaptive benefit, have evolved from their utility for responding to environmental changes.[[379]](#footnote-380) There is a debate here though; do the categories of emotion exist as ontological, causal agents in humans and animals, or are these categories instead *effects* of other causal factors and organized as such by human minds?[[380]](#footnote-381)

 An alternative view to BET considers the categories of emotion to be epistemological rather than ontological, where emotional responses are categorized by the way they feel or appear. This is the view of Social Constructionist Theory (SCT) which claims there are no preestablished causal categories of emotions which have emerged from evolutionary processes. Instead, emotions are outcomes of the same physiological systems which give rise to other cognitive processes.[[381]](#footnote-382) These affective responses are subsequently labelled as belonging to a particular category of emotion based on similarities and patterns which arise in a regular or predictable way.[[382]](#footnote-383) This view has origins in the early psychology of William James and Wilhelm Wundt, where emotion words are considered misleading as they inspire thinking in an *essentialist* manner.[[383]](#footnote-384) Since then, this theory has grown in popularity as no evidence has indicated a one-to-one correspondence between bodily states and emotional categories.[[384]](#footnote-385) Furthermore, brain imaging studies have failed to uncover localized brain regions or centres for basic emotions.[[385]](#footnote-386) Given this, categories of emotion and their terms like ‘sadness’ and ‘anger’ are considered to be “technical terms” and are used to categorize outcomes of physiological and cognitive processes.[[386]](#footnote-387) Words for emotion categories do not refer to causal mechanisms which produce these states, but instead, mental states which arise from attending to thoughts and feelings related to affective states.[[387]](#footnote-388) Thus, attention and language contribute significantly to the way we think about emotions, as to label an affective state, it must be in the focus of attention.[[388]](#footnote-389)

 In SCT, the foundation which generates affective states and emotions is called *core affect* which involves interactions between two dimensions: pain/pleasure or *valence*, and excitement/relaxation or *arousal*.[[389]](#footnote-390) These dimensions are generated by the body from specific physiological mechanisms which have been selected for by evolutionary processes. For example, physical pain is caused by the activation of nociceptors, a type of nerve cell found in the skin and tissues of many animals.[[390]](#footnote-391) The physical pain experienced by a particular stimulus, like the thorn of a plant or stinger on a bee or wasp, signals the presence of an entity capable of causing harm to the individual. Any affective reactions or emotions arising from the processing of sensory information creates an association between causal factors and their effects within the body, providing the individual with a source of information about elements of the environment.[[391]](#footnote-392) Individuals stung by a wasp may develop a fear of these insects in an effort to avoid interacting with them in the future. Alternatively, this individual may not feel a sense of fear upon seeing wasp, if they were indoors and behind a pane of glass. As such, though the body and its physiological processes give rise to core affect, the emotions and subjective experiences they produce also depend on the context in which they occur.

 Concepts related to emotion and affective states thus emerge from noticing physiological regularities and labelling subjective experiences.[[392]](#footnote-393) According to SCT, categories of emotion like *fear* and *anger* emerge from noticing the ways in which objects or situations generate affective responses and motivate actions.[[393]](#footnote-394) These concepts are useful for emotional self-regulation, working toward achieving a goal,[[394]](#footnote-395) as well as considering the ways in which others may experience certain types of situations.[[395]](#footnote-396) In humans, emotions become articulated in concepts and language, where these ideas and the ways they are expressed are influenced by background knowledge and social norms.[[396]](#footnote-397) These variables influence the way emotions manifest and are experienced at any given time, and as such, one’s conception of an emotional event is highly *heterogeneous*.[[397]](#footnote-398) For example, one instance of fear may feel or be outwardly expressed distinctly on different occasions, despite both being appropriately experienced and labelled as ‘fear’. While both instances of fear involve the expectation of painful or negative stimuli,[[398]](#footnote-399) the way an individual’s feelings are outwardly expressed may differ due to circumstance. Moreover, the manner in which individuals describe their feelings can also vary in *granularity*,where terms may be described with *high-granularity*,discrete and specific, noting slight differences between states, or *low-granularity,* where affective states are described vaguely through general terms, such as pleasure or displeasure.[[399]](#footnote-400) Together, these considerations indicate a number of variables present in the process of conceptualization and interpretation of affective states, where labels for emotions are ascribed based on contextual or situational factors and sociocultural norms.

 Overall, the debate between the BET and SCT views continues today, and attempts to reconcile these two perspectives into one theory have also emerged.[[400]](#footnote-401) Though the debate lingers, adherents to each perspective do not deny the significance of the other theory. Proponents of BET agree that social norms shape the way emotions are expressed, and proponents of SCT acknowledge the significance of biological patterns which are responsible for shaping and characterizing emotion categories. Each position considers the other theoretical stance to be theoretically relevant; however, to what degree is part of the debate.[[401]](#footnote-402) Moreover, there are also variations on BET, where some are interested in maintaining the idea of basic emotions while refuting that they exist as natural kinds.[[402]](#footnote-403) Overall, though the debate continues, it remains uncontroversial to claim that the brain and its cognitive faculties, along with the body and its physiological processes, work together to give rise to affective states which typically motivate individuals to perform certain actions.[[403]](#footnote-404)

 To demonstrate the relationship between the brain and body, consider the example of *fear*, an arguably paradigmatic emotional experience. Fear involves a particular physiological response profile for organisms to generate adaptive behaviours for avoiding harm. Upon detecting a stimulus which indicates a potential threat, a region of the brain called the *amygdala* sends a cascade of changes throughout the brain and body. While the amygdala is involved in these responses, it also responds to the detection of novelty and rewards, indicating its role involves more than generating fear responses.[[404]](#footnote-405) Moreover, not every instance of fear activates the amygdala.[[405]](#footnote-406) It is, however, associated with the activation of the hypothalamic-pitutary-adrenocortical axis (HPA axis) in response to a perceived threat.[[406]](#footnote-407) Upon the recognition of a stimulus, signals from the brain travel down the spinal cord to release hormones from a region known as the *adrenal* *cortex* located above the kidney.[[407]](#footnote-408) These hormones, epinephrine and cortisol, generate a range of multifaceted physiological effects, such as an increase in heart rate, blood pressure, respiration, glucose production, and the suppression of immune system functions.[[408]](#footnote-409) In addition, the relaxing and expanding arteries allow more blood to flow throughout the body, delivering oxygen and nutrients to muscle tissue to facilitate specific adaptive strategies. These processes all contribute to the subjective experiences of an emotional state in response to a stressful stimulus.[[409]](#footnote-410) From the subject’s point of view, a racing heart and increase in sweat production feels like heat in the body and an abundance of energy. Moreover, epinephrine and cortisol bind to receptors in the brain, including amygdala and hippocampus, which regulate the activity along the HPA axis.[[410]](#footnote-411) If the stimulus indicating a threat diminishes or changes, activity in the HPA axis adjusts accordingly, slowing the release of epinephrine and cortisol and allowing the body to return to a state of rest. This example of fear clearly demonstrates the way the body and brain coordinate to give rise to physiological and affective states which facilitate adaptive responses to perceived threats. Moreover, the body and its physiological processes consist of an interactive system of feedback and modulation, where brain regions regulate physiological activity and contribute to the conceptualization of feelings.

 From the internal feelings of fear, humans can control how they respond to subjective feelings, to a degree. While it can be difficult to control a racing heart, some outward expressions can be regulated or suppressed, such as the motivation to flee from a situation. Social factors influence how emotions are felt and expressed, in addition to the ways in which emotions are labelled and recognized. Different cultures regulate emotional expressions in different ways, depending on social norms. As mentioned in the previous chapter on empathy, certain Asian countries do not permit expressions of anger, while other cultures may deem these expressions to be more permissible. Expressions of fear, on the other hand, may be consciously controlled in instances of combat and war, where soldiers exhibiting fear may instill confidence in the enemy. When dealing with certain wild animals, like cougars and black bears, fear-based responses like running away may entice the animal to pursue an attack, as the individual can be perceived as a non-threatening target.[[411]](#footnote-412) It is recommended that when dealing with these animals, acts of aggression indicate the presence of a threat or a difficult pursuit. In this way, regulating emotions depends on contextual factors, from the situation at hand to sociocultural norms, subsequently shifting how emotions are experienced and conceptualized.

 From this brief analysis of a significant debate in the theory of emotions, it is reasonable to conclude emotions involve a set of behaviours and inner experiences aimed at responding appropriately to the detection of environmental stimuli. Subjective experiences associated with emotions are caused by or associated with physiological events or processes, such as a racing heart. As such, the body and mind interact with one another to give rise to affective states which can be ascribed a label, as per the effects of cognitive and physiological processes. Therefore, it seems that the preferable approach for adding emotional processing to iCub would be one which follows SCT. This is due to the generative flexibility offered from the two elements of core affect, namely valence and arousal, supporting a wider array of affective states than if BET were to be implemented instead. Since the categories identified by BET can be created from core affect, this approach would avoid the need to preprogram categories of emotions into the robot while retaining the ability to recognize and respond to the six categories identified by BET.

 Even if a version of SCT were to be implemented into iCub, however, the outcomes produced from this approach are insufficient for grounding the meanings of words related to emotions. The reason for this is due to how information about emotions is generated. All information about emotions and affective states remains *exogenous* rather than *endogenous*, arising from human expressions and concepts rather than the robot’s own body and subjective experiences. In biological organisms, the body and its physiological processes directly generate information *about* stimuli detected within the environment to better their chances at survival and reproduction. Consequently, any information a person knows about emotions is predicated on their own subject feelings, and because iCub lacks feelings and phenomenal experiences, it cannot appeal to its own knowledge generated from bodily functions. For iCub, all knowledge of affective states comes from human teaching, whether gained through interactive experience, or written in the robot’s code. Therefore, the robot cannot understand concepts related to affect, unlike other concepts like ‘cup’ or ‘drive’, words relating to external objects and actions. Since emotions are generated internally from the interaction of physiological systems, the referent of words related to affect is absent, leaving the word ungrounded.

 The relationship between the robot’s body and mind is reversed. Rather than generating the robot’s mind and behaviour from the coordination of bodily processes, the robot’s mind instead remains independent from the body. All behaviours and actions are supported by human-written instructions, and while this approach has many useful applications for robotics, diverges considerably from biological processes. As a result, attempts at replicating certain capacities in robots, like socialization and empathy, are limited by this inverted relationship between the mind and body. The reason for this outcome is arguably due to the perspective adopted by robotics engineers, as a machine’s parts are ideally assembled in ways which are modular and decoupled from one another. This modularity enables engineers and developers to easily replace and test a particular component separately, gaining specific knowledge about the part in question. This relationship between functionality and embodiment is distinct from animals and their physiological processes, since in biological agents, a particular function or process arises from physical mechanisms inherent to embodiment. This high degree of coupling or dependency is due to evolutionary processes, where physical materials give rise to biochemical functions which constitute physiology. In robotics engineering, this degree of interconnection between functionality and its physical implementation is avoided for practical reasons. Given this, however, robots like iCub do not sufficiently model the biological processes which are required for developing analogues of emotions, empathy, and sophisticated social behaviours. To produce these outcomes, a new approach to robotics engineering is required. One which generates cognitive processes and behaviours as a result of the robot’s physical body interacting with and responding to aspects of its external environment. For emotions, it is the body’s reaction to stimuli which ultimately grounds the meanings of these words and concepts, an idea which will be explored further in the following chapter.

 In addition to grounding words and concepts related to emotion, affect should be incorporated into social robots given the significance of affective processing for cognition in general. The significant contributions of psychologist Antonio Damasio and his *somatic marker hypothesis* indicates affective processes contribute to cognitive abilities which are unrelated to emotion. Experiments conducted during the 1990’s indicated decision-making abilities were negatively impacted in individuals with damage to frontal regions of the brain associated with emotional expression.[[412]](#footnote-413) From this, Damasio suggests that rather than existing as separate from “rational” cognitive processes, emotions and emotional experiences significantly contribute to reasoning tasks.[[413]](#footnote-414) Given the evidence of a high degree of coupling between emotions and reasoning, it is not enough to programiCub and other social robots with a theory of emotions, and instead, they must *feel* emotions as generated from the bodily processes. This approach would likely also improve the ways in which the robot operates and performs behaviours, appearing to reason in a manner more similar to a human than a computer.

 Without emotion, iCub will likely produce behaviours which appear to be inappropriate or insufficient, indeed acting *robotically* during instances where affective sensitivity is required. One of these cases is during acts of empathy. As discussed, empathy requires the recognition and adoption of affective states as perceived in another. It relies on experiencing for oneself how another person is feeling within a particular interaction, where the observer, as a living being, is able to experience subjective states for themselves to understand their meaning. These experiences and subjective feelings are responsible for grounding behavioural cues and acts of empathy, as without an understanding of what emotional expressions refer to, any act of empathy is a mere simulation. Since iCub cannot appeal to its own knowledge of ‘sadness’ or ‘pain’, it must rely on humans to provide it with representations of these feelings. These representations could be implemented in code or by learning the behavioural cues related to specific emotions as exhibited by people. Any perceived understanding of concepts related to emotion would thus remain a very narrow representation of the ways in which affect manifests in animals including humans. For example, a smiling face is yet another symbol or representation of a real affective state, one which iCub does not have access to. Experience is therefore required for emotion, and emotional experience is required for empathy, as it requires one to adopt the perspective of another. Since this is missing in iCub, any act of perceived robot empathy remains a simile of a true instance of perspective-taking. It is important to note that this principle will still apply when robots of the future become more sophisticated at detecting and responding to human behaviour. Though these similes may one day appear to be convincing and impressive, any instances of empathy or emotion will remain a simulation.

 These limitations indicate that a new approach to creating robots is required if they are to understand human emotions. The following chapter provides an alternative approach to building robots in a manner which is analogous to human and animal physiology to better model the processes which generate affect and emotion. This approach, and its corresponding robot prototype, is a better version of embodiment than iCub because the robot’s hardware gives rise to functionality, analogous to the way cognition and behaviours manifests in humans and animals. To further motivate this new approach, a brief discussion of the underlying principles involved in both living organisms and cybernetics will be considered. By appealing to the self-organizing processes and feedback systems in both domains, an improved model of living beings for building social robots can be identified.

 In conclusion, this chapter examines the history of artificial intelligence to better understand the direction taken for social robots created today. From a history of computers, robot behaviours emerge in a distinctive manner from the way behaviours emerge in living organisms, despite apparent similarities. Though outward appearances may indicate functional similarities, computers and social robots are built from rules and instructions. Although experiential learning and human tutelage for generating new behaviours grew in appreciation over time, the relationship and interactions between computer code and robotic bodies indicates an insufficiency for certain tasks. Despite iCub being able to recognize emotional expressions, the meanings of these expressions, and words used to describe them, are not understood by the robot. This is because terms related to emotion and affect do not refer to external aspects of the world, and instead refer to internal processes and subjective feelings. Though theories of emotions can be programmed into robots like iCub, the requisite feeling for grounding ideas related to affect is absent. As such, a new approach to building social robots is required, otherwise, their inherent limitations will become even more apparent, especially during acts of empathy. Embodiment and emotion, for humans, is not ancillary nor separate from cognition, but is instead foundational for behaviour. The current approach taken by social robots demonstrates the opposite: the robot’s body remains a shell for its computer-generated mind to govern. Historically, the development of social robots and AIs over the 20th and into the 21st century witnessed a prioritization of behaviours and cognitive capacities, only to be followed by the development of a robotic body. Because biological organisms develop in the opposite manner, where cognitive capacities arise from bodily functions, a new approach is recommended if we are interested in overcoming inherent limitations identified in social robots. Affective states and the physiological processes which give rise to them are fundamental for behaviour, whether related to affective processing or not, suggesting iCub and other robots are insufficiently embodied for acquiring the requisite capacities for socialization.

Chapter 4 – Embodiment for Robot Experience

 To ground the meanings of words, specifically those related to emotions, the body of a robot must subjectively experience the stimuli encountered in its environment. To accomplish this, a brief investigation of self-organization in biology is necessary as background for incorporating experiences to robots. The specific form of embodiment required for subjective experience is one which includes associative learning and signals representing pain and pleasure. Experiences thus arise from a robot learning how various stimuli impact the body, grounding the meaning of emotions through the associations between stimuli and sensations that it learns.

4.1 – Autopoiesis for Experience in Living Beings

This section presents an overview of a proposed explanation of life as a phenomenon in the natural world. As such, we can identify the requirements for embodiment, a precondition necessary for its role in generating experiences. In Chapter 3, it was demonstrated that embodied computers are not embodied in the way living organisms are, as the body of a robot is secondary for the primary purpose of creating minds and behaviour. Below, we will broadly examine life and embodiment to determine how experiences and the mind arise from living bodies; a strategy inverse to prevailing approaches to social robots. To start, let’s investigate the foundational principle involved, *autopoiesis*, or the capacity for self-organization. This involves a collection of physiological mechanisms interacting with one another to maintain a variety of functions required for the system. If variations arise within these processes, they can be offset by adjustments to different mechanisms within the system. Through evolutionary processes, organisms became better able to respond and adapt to changes, resulting in experiential learning. Additionally, subjective experiences which accompany the detection of stimuli and environmental changes assisted this process by informing individuals about what a particular stimulus means. These associations lead to responses which regulate interactions with the environment, thus increasing the likelihood the individual remains alive and will potentially reproduce. Organisms are inherently invested in the effects caused by environmental changes to their bodies. As such, self-organization can be considered a foundation for the grounding of meanings. For example, if a stimulus negatively impacts an aspect of the organism’s functionality, sensory receptor signals will deem it as harmful, motivating avoidance. In this way, elements of an environment gain value and meaning as they contribute or detract from their survival, as depicted by subjective experience. Therefore, the self-organization underlying the bodies of living beings establishes the meaning of stimuli, where behaviour emerge as outcomes from experiences induced by sensory mechanisms.

 The general principle supporting living things is an ability to self-organize on a number of different levels of systems, from cells to organs to more complex physiological constructs like the circulatory system. The concept of autopoiesis was first developed by Humberto Maturana and Fransisco Valera in Chile in their book *De Maquinas y Seres Vivos* in 1972.[[414]](#footnote-415) Their work, however, would not receive wide-spread attention in English speaking countries until a paper was published in the journal *BioSystems* in 1974.[[415]](#footnote-416) *Autopoiesis and Cognition*, an English version of their 1972 book,was published in 1980[[416]](#footnote-417) and has since been slow to be adopted into mainstream science.[[417]](#footnote-418) Some claim that this is due to biology’s tendency to study life from the perspective of populations,[[418]](#footnote-419) reproduction, and evolution[[419]](#footnote-420) instead of the underlying mechanisms which lead to these outcomes. Rather, autopoiesis offers an explanation for a more fundamental level of biology by investigating the organization of individuals which reproduce and comprise populations.

 The explanatory strength of autopoiesis is due to its ability to identify a concept to distinguish living things from non-living things, providing an explanation distinct from other *descriptive* accounts for articulating what life is. Descriptive accounts often provide lists of properties characteristic of living organisms, like metabolism, reproduction, self-maintenance, containing genetic material like DNA, and evolving via mutations and natural selection.[[420]](#footnote-421) Maturana claims that simply describing the characteristics of living systems cannot sufficiently articulate a definition of life as a physical phenomena.[[421]](#footnote-422) Moreover, he claims that enumerating the properties of living organisms is an impossible task.[[422]](#footnote-423) Due to these short-comings, living systems should instead be considered as a unity, “an entity distinct from a background”[[423]](#footnote-424) and created by a physical boundary. In fact, the idea of a boundary is essential for autopoiesis, where the delineation between interior and exterior is what separates an individual from other elements within the environment.[[424]](#footnote-425) In a cell, for example, the cell membrane or outer layer creates a boundary which separates the inside of the cell from the outside.

 So rather than focusing on physical properties of living organisms, as in, their qualities or attributes, Maturana and Valera are instead interested in organization and relations between components.[[425]](#footnote-426) As such, these systems can be realized or instantiated in different mediums,[[426]](#footnote-427) like software as observed in the domain of *artificial life.* The concept of interest is the unity which arises from the self-organization which emerges from a network of physical interactions. The necessary properties of the components are not of interest, but rather the necessary *organization* for systems to become a unity is of primary concern. This circular organization ensures the production and maintenance of the relations which give rise to the same organization which produces these relations.[[427]](#footnote-428) As a result, the entity is *autonomous*, able to maintain its identity through the “active compensation of deformations”[[428]](#footnote-429) or perturbations due to and despite physical interactions within the environment.[[429]](#footnote-430) The regeneration required to maintain a network of interactions occurs inside the boundary, and this demarcation is made and sustained by these processes.[[430]](#footnote-431) It is also semipermeable to let in physical materials,[[431]](#footnote-432) as these self-sustaining systems still require incoming nutrients and energy, and as such, are operationally open systems.[[432]](#footnote-433) An operationally closed system, in contrast, would neither require nor allow the incorporation of physical inputs or materials. There is, then, a dependence on the environment and external mediums in which these systems reside.[[433]](#footnote-434) The fact that autopoietic systems are operationally open means the external environment shapes the internal structure of the organism, where changes within the external environment give rise to and promote internal changes.[[434]](#footnote-435) Provided these changes do not disintegrate the relations which are necessary for their organizational capacity, the system is able to compensate for alterations which follow from environmental variation.[[435]](#footnote-436) The relations generated by a network of processes which produce components of the autopoietic network are thus the most significant aspect of autopoietic systems.

 In contrast, *allopoietic systems* are ones whose organization is not autonomous or self-sustaining but are created by means external to the system itself.[[436]](#footnote-437) A car, for example,[[437]](#footnote-438) as a unity is produced by processes independent from the organization and operation of the car itself, namely a factory with assembly workers and other machines. Computers and robots are also allopoietic systems, requiring creation and maintenance from humans or other allopoietic machines, as they are not autonomous and instead are reliant on some degree of human intervention for their continued operation. The distinction between autopoietic and allopoietic systems is significant, as it indicates a key difference between animals, including humans, and manmade artifacts like robots. Since artifacts like computers and robots exist as objects and cannot function without some degree of intervention from human action, they are a qualitatively different kind of system than living organisms. This difference has important implications for how we should think of social robots as they continue to improve over time, an idea which will be further discussed in the following chapter.

 Conceptually, autopoiesis can also account for why offspring may not be identical to the organisms which created them. In reproduction, some components might be slightly different due to mutations, however, the functionality they generate must be sufficient to maintain self-sustainability.[[438]](#footnote-439) Autopoietic mechanisms can compensate for variation and change by adjusting other processes which give rise to necessary functions for an organism’s continued survival. Reproduction and evolution at the level of the individual are not essential for self-organization, and instead, the ability to reproduce and evolve emerges from systems capable of self-organization.

 Thus, biological processes interacting with one another to support autopoiesis enable organisms to remain alive and reproduce. These processes need to be renewed and maintained, and the individual requires mechanisms to facilitate the fulfillment of these needs. At the level of the cell, one of these mechanisms involves the intake of nutrients to transform them into components which restores depleted resources. Similarly, multicellular organisms require the intake of food where digestion breaks down substances into components to be used by the body and its physiological processes. Thus, any damage or disruption caused by the depletion of components can be restored, provided individuals are able to consume the necessary resources which facilitate this restoration. Though the biological cell was the inspiration for autopoiesis, the concept transcends many domains, from individuals to social dynamics,[[439]](#footnote-440) although this remains contested.[[440]](#footnote-441) Overall, any system which is characterized by a set of relations which give rise to self-organization and autonomous functionality is said to be autopoietic.

 To acquire nourishment, sensory mechanisms enable it to detect environmental changes associated with nutrients, and later in the phylogenetic tree, an ability move around the environment and seek food.[[441]](#footnote-442) Early lifeforms without an ability to move, such as sea sponges, were able to detect the presence of food; however, organisms without these sensory mechanisms were left to chance for acquiring necessary resources. Organisms without these mechanisms risk a higher degree of failure to meet their needs, increasing the likelihood of dying as a result. Even if the individual managed to reproduce, its offspring would likely share these missing capacities and thus would not fare as well as individuals inheriting mechanisms for the detection of food.[[442]](#footnote-443) Presumably, an ability to detect environmental changes associated with acquiring food and other necessities to sustain physiological processes was selected for by evolutionary processes. Organisms lacking sensory mechanisms were more likely to die off prior to reproduction and go extinct as a species.

 As such, a degree of environmental awareness is required for optimizing the ability to find nutrients and other necessary resources like mates and shelter.[[443]](#footnote-444) Hence, species with sensorimotor mechanisms became capable of traversing their environment, thus maximizing the chances of satisfying their requirements. As such, and over time, a rudimentary environmental awareness emerged, pertaining to both internal bodily states and external awareness of environmental changes.

 To facilitate the detection of environmental changes, a specialized cell evolved to respond rapidly to stimuli.[[444]](#footnote-445) The neuron and interconnected neural networks evolved to generate reflexes, automatic responses to stimuli which rapidly transmit information to generate basic motor patterns.[[445]](#footnote-446) The firing of one neuron would transmit a signal to nearby neurons which caused parts of the body to move about, a response which facilitates the acquisition of resources or escaping dangerous situations. At first, these networks were distributed throughout the body without a central structure like a brain, however, over time central nervous systems would develop.[[446]](#footnote-447) As the bodies and sensory mechanisms of organisms developed from evolutionary processes, additional neuronal networks and structures were required to process the information being transmitted throughout the body.[[447]](#footnote-448) The Cambrian explosion, occurring around 560 million years ago,[[448]](#footnote-449) saw the diversification of animal species with advanced central nervous systems and sensorimotor programs for detecting and adapting to environmental changes.[[449]](#footnote-450) From invertebrate species such as sponges and worms, vertebrates with central nervous systems evolved to better detect and capture prey animals,[[450]](#footnote-451) culminating in ever improving sensory mechanisms related to vision, hearing, touch, and chemoreceptors for smell and taste.[[451]](#footnote-452) While nociceptors for detecting pain likely developed prior to the Cambrian explosion to detect noxious or harmful stimuli, the mechanisms for pain and pleasure would also develop further during this period of time.[[452]](#footnote-453) Additionally, cognitive capacities like memory and attention would continue to develop over this same period, eventually resulting in internal presentations of stimuli to better respond to elements of the environment.[[453]](#footnote-454)

 It is from this prodigious and diverse evolutionary history that humans and their sophisticated nervous systems emerged. Brains with large neocortices, neuronal structures surrounding lower brain regions like the evolutionarily older *limbic system*, enabled the development of sophisticated cognitive abilities. Moreover, advanced neocortices introduced an improved capacity to create and use tools and think abstractly. Humans also benefited from our evolved social tendencies, allowing us to work together towards different shared goals. To maintain social harmony, however, more complex norms and practices were increasingly required, and as such, our communication skills and linguistic capacities also needed to evolve. The information generated from these practices, when combined with our ability to communicate, resulted in cultural information or ideas which could be transmitted to others. One way to describe this phenomenon has been through the use of the word *memes*, as coined by biologist Richard Dawkins in his book *The Selfish Gene*.[[454]](#footnote-455) He postulated that as units of information, memes mutate over time when passed between individuals and groups, evolving similarly to genetic material through replication. Since the introduction of the term, however, a debate has emerged over the details of memetics,[[455]](#footnote-456) such as the nature of their replication.[[456]](#footnote-457) Nonetheless, the general notion of the spreading of ideas as a significant factor for human cultures and societies helps explain the development of humans and their societies. Together, the evolution of physical bodies and spread of cultural information further developed capacities and innovations like tool creation and social practices, resulting in developments like agriculture, legal systems, art, and advanced technology.

 In 1991, Varela published *The Embodied Mind* with coauthors Evan Thompson and Eleanor Rosch, generating a new conception of minds and behaviour by establishing connections to autopoiesis. Inspired by the writings of French phenomenologist Maurice Merleau-Ponty, their discussion of minds and behaviour is one which considers both biology and phenomenology.[[457]](#footnote-458) Doing so provides a perspective which considers minds as *enactive*, where cognition arises from the interaction of the body and the world in which it lives.[[458]](#footnote-459) To motivate this stance, the first chapter provides a quote from Merleau-Ponty which provides a glimpse into his contributions to phenomenology:

Perception is not a science of the world, it is not even an act, a deliberate taking up of a position; it is the background from which all acts stand out, and is presupposed by them: The world is not an object such that I have in my possession of the law of its making; it is the natural setting of, and field for, all my thoughts and all my explicit perceptions.[[459]](#footnote-460)

 Cognition is an evolved capacity from autonomous, living organisms and their interest in the world, since the environment can impact the self-organizing processes which constitute their being. Experiences of the world are a product of an awareness of the ways in which the body and its physiological systems detect and respond to changes in the environment.[[460]](#footnote-461) The mind and its contents result from this primordial awareness, where acts of reflection further allow individuals to better understand the qualities of these experiences. As such, introspection assists individuals in understanding the relationship between their bodies and mental contents.[[461]](#footnote-462) By focusing one’s attention on what the mind is doing as it is occurring, greater insight on the human experience can be gained.[[462]](#footnote-463) As a discipline, phenomenology analyzes and describes the contents of experience as they are perceived from the first-person perspective.

 Rather than conceiving of a mind as an input-output machine, it should instead be understood as emerging from a network of physiological processes, all of which self-organize for the sake of responding to environmental demands. Self-organization occurs on many biological levels,[[463]](#footnote-464) from cells to organs to systems of organs working together, where this nesting produces a multilayered, complex system which operates as a unity or integrated whole. In animals, cognition is produced by the nervous system and aims to maintain this multi-level self-organization through the avoidance of harms, along with an attraction toward beneficial resources and activities. For example, feelings of hunger motivate the intake of food to replenish the nutrients and resources required to maintain autopoiesis. As a result, we see a *structural coupling* or a close and inseparable relationship between the functional structure of living organisms and regularities within the environment.[[464]](#footnote-465) As organisms evolve, their physiology shifts to meet environmental demands, and as such, these outcomes are closely linked to elements of the environment.

 A tension has long existed between scientific studies of cognition and philosophical examinations of experience from the first-person perspective. By considering both domains, the idea of enactive minds describes the connection between inner and outer, subjective and objective. Verifiability is a key component in scientific disciplines; however, one’s *lived* *experience* cannot currently be examined nor verified by external means. That said, by systematically describing the way subjective experiences appear from the first-person perspective, we can understand the ways in which these experiences are predicated on the body’s morphology and its physiological systems. The domain of phenomenology, as introduced in Chapter 2, is thus important to consider to better understand human minds and their behaviours. One significant concept which has greatly influenced phenomenology is Martin Heidegger’s *Dasein* or “being in the world,”[[465]](#footnote-466) as it views humans as living within a wider environment and thus deeply influenced by it.[[466]](#footnote-467) Because human cultures are a part of this wider environment, each human individual understands itself as existing within some culture and participating in a specific way of being.[[467]](#footnote-468) In contrast, scientific examinations of humans and their behaviour aim to understand “context-free elements, cues, attributes, features, factors, primitives, etc., and relate them through covering laws, as in natural science and behaviourism, or through rules and programs as in structuralism and cognitivism.”[[468]](#footnote-469) Though the sciences and humanities including phenomenology begin from distinct vantage points on questions related to human life and behaviour, both must be considered to sufficiently address these forms of inquiry. While phenomenology and its postulates cannot be reduced to and be fully articulated in scientific terms, a connection can be identified and articulated by concepts like autopoiesis. It suggests that through a variety of physiological self-organizing processes within the body, subjective experiences manifest as internal presentations of elements of the external world. Since biological organisms are capable of responding and adapting to environmental demands, their bodies and behaviours are products of environmental pressures and regularities influencing physiological processes.

 Evan Thompson would further the connection between phenomenology and biology in *Mind in Life* published in 2007. Originally, this book was coauthored by Varela, however, in 1998 he would step away due to health problems, leaving Thompson to revise and complete the book himself.[[469]](#footnote-470) Thompson argues that phenomenology needs to be able to interpret and understand its inquiry in relation to scientific domains, and that mind sciences can be informed by the analysis of phenomenological considerations.[[470]](#footnote-471) By appealing to autopoiesis, he explains how the mind emerges from self-organizing processes which interconnect the brain, body, and environment, resulting in a self-determining individual who remains nevertheless continuously involved with its environment.[[471]](#footnote-472) As the individual is dependent on aspects of the world for its continued survival, and is harmed by some of its features and contents, value and meaning is established for individuals.[[472]](#footnote-473) Sugar, for example, gains its value as food and fuel source because it is registered as a nutrient which satisfies an organism’s metabolic needs.[[473]](#footnote-474) The evolved pleasant experiences of consuming sugar indicate a beneficial element to interacting with this chemical, motivating individuals to consume more of it to meet their biological needs.

 Included in the environment, for humans and some animals, is a social element which adds complexity to the dynamic between internal and external environments. The actions and inactions of others have the ability to impact the way individuals experience the world and subsequently behave within it.[[474]](#footnote-475) This added complexity is due to the way cultural practices and norms evolve over time. Since culture involves systems of information, the interaction between individuals and groups, along with their ideas and practices, further contributed to the complexity of cognitive capacities, behaviours, and cultural products like technology.

 Over time and as a result of the work of Varela and others like Thompson, a growing understanding and appreciation of environmental influences on the body shifted conceptions of the mind and brain, giving rise to *embodied cognition* as an approach to scientific research*.[[475]](#footnote-476)* From this perspective, individuals and their behaviours are seen as outcomes of physiological systems fluctuating in response to shifting environments. Social and cultural factors also play a role in shaping human thinking and actions taken in response to environmental conditions. Rather than conceiving of the mind as a separate entity which governs the body, as proposed by Descartes, contemporary views see the mind as emerging from bodily processes over the course of human evolution and through childhood development, occurring in particular sociocultural contexts and physical environments. Thus, behaviour is not the outcome of a biological computer, but the organism as a complex system of interrelated subsystems.

 Therefore, an organism’s awareness and ability to experience the world emerged through evolutionary processes to facilitate the individual’s continued survival, where these capacities are generated from interconnected, self-organizing physiological processes. The capacity to detect and respond to environmental changes facilitates the continued functioning of necessary physiological processes. One form of sensorimotor functionality is the association of pain and pleasure signals to specific stimuli, consequently imbuing them with meaning and significance for the sake of the individual’s survival. It is this association between stimuli and their effects on the body and its processes which gives language and symbols their meaning, as they refer to objects or phenomena which carry the potential to impact these self-organizing processes. This brief discussion of autopoiesis and biological development aims to explain and motivate the proposed solution to building a robot capable of machine empathy. The next section continues the story of Varela, as he was indirectly related to developments in robotics which gave rise to iCub. Given the issues identified with the aforementioned embodied robot iCub, a new approach is required, one which takes *embodiment* further to ground the meanings of emotions.

4.2 – Self-Organization in Machines

The principle of self-organization has been applied to machines and software, first beginning with cybernetics in the 1940’s and later in a domain called *artificial* *life* (ALife). As mentioned in the previous chapter in the section on the history of AI, cybernetics played an important role in the history of AI with the McCulloch Pitts neuron, a mathematical model of neuronal activity. In fact, cybernetics had inspired Varela as he learned about it while working on his PhD at Harvard during 1968 and 1969.[[476]](#footnote-477) Varela would eventually go on to assist in the development of ALife as a new domain of research, where contributions made by Rodney Brooks would introduce embodiment to AI. Despite the promising directions proposed by cybernetics and ALife, the significance of emotions for embodiment was overlooked, and as such, led to the development of robots without the ability to understand what emotions are. This section returns to the mid 20th century with an examination of cybernetics prior to presenting a brief history of ALife to demonstrate the promising, albeit insufficient, direction robotics has pursued since the advent of the McCulloch Pitts neuron. While this direction led to the creation of iCub, it nonetheless failed to notice the significance of emotion for behaviour.

 As mentioned in the beginning of the previous chapter, in 1948 and before the advent of AI, Norbert Wiener published *Cybernetics: or Control and Communication in the Animal and the Machine*. ‘Cybernetics’ comes from the Greek word *kybernetes* which means “steersman” and refers to the person steering a boat or ship.[[477]](#footnote-478) The idea is that this role watches to see where the ship is headed and corrects the course accordingly by using visual feedback. The word *governor* is also derived from *kybernetes*.[[478]](#footnote-479)Thus, cybernetics concerns itself with mechanisms for control and regulation through relations and the flow of information.[[479]](#footnote-480) Instead of focusing on what systems are made of or what the system *is*, cybernetics is interested in what systems do.[[480]](#footnote-481) This interest in functionality and behaviours means that cybernetics can be applied to a number of domains, from engineering to biology to sociology.[[481]](#footnote-482) As such, the domain has influenced many disciplines in modern sciences, including computer science, information theory, cognitive science, artificial intelligence and artificial life.[[482]](#footnote-483)

 The specific functionality of interest to cybernetics is circularity, where feedback processes use system outputs or effects as inputs for the system.[[483]](#footnote-484) The systems characterized by these circular processes are self-regulating and able to maintain their stability through feedback loops.[[484]](#footnote-485) Given its interest in functionality, cybernetics is interested in the similarities between machines and living systems, where autonomous agents are capable of regulating their own behaviours through circular processes.[[485]](#footnote-486) To do so, these *automata* receive information from the external environment and use it to perform actions, and are thus *coupled* to the world in which they exist.[[486]](#footnote-487) Elements of the environment play a significant role in governing the behaviours of automata, as the responses generated are in relation to these environmental factors.

 An example of an automatic device is a thermostat which uses sensors to measure air temperature.[[487]](#footnote-488) The reading is compared to the set threshold, and heat is generated if the value is below the desired temperature. Once the heat has increased to meet the threshold, the thermostat detects the change and shuts the heater off. If the temperature drops below the threshold, the thermostat repeats the process automatically. The difference between the actual air temperature and set threshold is deemed the *error* and the thermostat’s behaviour aims to reduce this value. This functionality is called *negative feedback* and is used by the system to generate or maintain a specific outcome by adjusting behaviours which reduce the error value. This phenomenon also observed in the Watt governor,[[488]](#footnote-489) a spinning device which regulates the amount of steam passed into a steam engine. It is comprised of two metal balls attached to upper and lower links, where these links are secured to a central sleeve which raises and lowers over an inner spindle as a result of the spinning action.[[489]](#footnote-490) Since the governor is attached to a valve, the centrifugal forces acting on the metal balls pulls the sleeve upward, subsequently closing the value to reduce the amount of steam passed to the engine.[[490]](#footnote-491) As the spinning slows, the central bar drops down causing the valve to close. In contrast to negative feedback, *positive feedback* increases the difference or *error* between two states or values.[[491]](#footnote-492) An example of positive feedback is the noise generated from a speaker when a nearby microphone picks up and amplifies the sound produced by the speaker.[[492]](#footnote-493)

 In humans and animals, the nervous system acts as a mechanism for the regulation of behaviour. As an integrated whole, this physiological system monitors behavioural outputs and adjusts motor actions accordingly based on the difference between desired outcomes and actual outcomes.[[493]](#footnote-494) This includes an array of sensory mechanisms, including an organism’s skin and body, both of which provide persistent feedback to self-regulate the organism’s own behavioural responses.[[494]](#footnote-495) For example, a cat can learn to pounce by noting the difference between its desired end-state, say leaping on top of a mouse, and its actual end-state, which could include falling short and missing it, allowing the mouse to escape. In this case, visual and tactile cues are processed by the cat’s nervous system and it is thus able to adjust its muscle movements on the next jump, reducing the error until it lands successfully on the mouse. Though this form of feedback and adjustment is notably different than engineered systems which can modify their behaviours as they are in operation, it nonetheless demonstrates the ways in which bodily systems use negative feedback for corrective measures. The cat must make additional jumps to reduce the error value, in this case the distance from the target, and is not able to correct its behaviour mid-jump. Through trial and error, however, the cat’s learning mechanisms enable it to close the distance between where it lands and where it wants to land. In this way, negative feedback is used by organisms to correct behaviours, accomplishing this in a slightly different way than devices like thermostats and governors.

 In his following publication *The Human Use of Human Beings*, released two years later in 1950, Wiener includes a discussion on the significance of affective states which motivate behaviours in animals. Referring to Ivan Pavlov’s influential study on associative conditioning, he notes that animal behaviour is often motivated by “emotion” which usually concerns food.[[495]](#footnote-496) Although many stimuli unassociated with food like certain sounds and visual cues do not produce a behavioural effect, a connection between the two may be established provided the stimulus is presented at the same time. The resulting association can be learned from a number of concurrent presentations, leading the animal to respond to the stimulus alone without the presence of food. Pavlov’s research led Wiener to conclude that these associations are created from “something important to the life of the animal: in this case, food,” though it is not required to generate the behaviour once the association has been learned.[[496]](#footnote-497) To reinforce his claim, he also discusses the same phenomenon with respect to pain by appealing to an electric fence to enclose cattle. Although a cow is strong enough to break the fence and escape, it does not because the pain generated from electric shock deters it from touching the fence.[[497]](#footnote-498) The cow learns the association between the fence and its painful effects, influencing its interest in escaping from the enclosure altogether. This discussion is interesting and worth mentioning because it highlights the significance of affect, which Wiener calls ‘emotion’, for motivating behaviour. As such, it serves as a causal mechanism for generating behaviour in animals, a notion which should be included in the design of robotics which aim to recreate humanlike abilities. The section which follows describes this functionality in further detail.

 Cybernetics would eventually lead to the creation of the domain of *artificial life* in the late 1980’s.[[498]](#footnote-499) Though the concept of self-organizing systems had been introduced to cybernetics by Heinz von Foerster in the late 1950’s,[[499]](#footnote-500) the implementation of these systems in computer software would not arise until the development of modern computers.[[500]](#footnote-501) After the discovery of DNA by Watson and Crick in 1953, a student of von Neumann, Arthur Burks, would develop abstract logical structures of self-reproduction in *cellular automata*.[[501]](#footnote-502) Consisting of a two-dimensional array divided into square cells, cellular automata would be programmed with a set of rules for self-reproduction, where cells would grow into unoccupied adjacent spaces within the array. Development on the mathematics of cellular automata would continue with the help of von Neumann and others, including Edgar Codd and John Conway.[[502]](#footnote-503) Conway would go on to create thewell-known *“*Game of Life” which, using specific configurations, aimed to increase the number of live cells within the grid space.[[503]](#footnote-504) In 1987, Christopher Langton would hold a conference on the “Synthesis and Simulation of Living Systems” which introduced a number of models for living systems, leading to the developing of ALife.[[504]](#footnote-505) The approach used in creating cellular automata was a novel development for its time. This bottom-upapproach directly contrasted the top-down, rule-governed functionality of symbolic AI which was still popular at the time.[[505]](#footnote-506)

 In 1979, Varela would publish *Principles of Biological Autonomy* which included a discussion of cellular automata as a model for simple autopoietic systems capable of creating and repairing self-enclosing boundaries.[[506]](#footnote-507) These formulations would provide an alternative basis for ALife, and Varela would credit von Foerster as inspiration for his and Maturana’s work on autopoiesis. Thus, congruency between animals and mechanical artifacts had been identified in practice, just as Wiener’s book title theorized forty years prior.

 In 1991, Varela and Paul Bourgine would organize a conference titled the “First European Conference on Artificial Life”[[507]](#footnote-508) where the proceedings would subsequently be published and titled *Towards a Practice of Autonomous Systems*.[[508]](#footnote-509) Included in these presentations was one by Rodney Brooks, asking whether techniques from ALife could be useful for generating programs to control robots by mimicking evolution.[[509]](#footnote-510) The reason for this suggestion was because robots at that time were unable to learn to adapt to dynamic environments, and new behaviours needed to be specified in code. Given that ALife had developed techniques for evolving new programs for robots in simulated environments, Brooks was interested in applying these techniques to physically embodied robots. Of particular interest was *genetic programming*, where behaviours could be developed in simulated environments and later implemented in physical versions of the robot.[[510]](#footnote-511) Genetic programming involves the incremental design and implementation of behaviours, where a minimal amount of architecture is written and tested before adding the next-simplest layer of behaviour.[[511]](#footnote-512) Since robots are required to adapt to their environment via machine learning, control structures could be developed through evolutionary means in simulated environments,[[512]](#footnote-513) removing the need of performing large numbers of “runtime trials” in physically-embodied robots.[[513]](#footnote-514) Machine learning, in this case, was generated through symbolic approaches to AI using the programming languages like LISP,[[514]](#footnote-515) unlike the machine learning techniques of today which involve neural networks in robots like iCub.

 Despite their shared interest in ALife, Langton and Varela held contrasting points of view on the discipline’s primary characteristic and research motivation. Langton’s interests were centred around framing life in terms of information processing, where a specific configuration of information reproduces itself to sustain life.[[515]](#footnote-516) Varela, on the other hand, considered information processing as a secondary factor of a system’s organization, working as an allopoietic submachine within self-organizing dynamics. Instead, Varela considers the most fundamental capacity of living systems to be autonomy.[[516]](#footnote-517) In the front matter of *Towards a Practice of Autonomous Systems*, he states that autonomous systems are better defined by the ways in which they act within the world and are shaped by environmental factors.[[517]](#footnote-518) The reason for this framing is because it corresponds to a variety of different autonomous systems, from cells and animals to human societies. Moreover, this characterization moves beyond the “disembodied abstractions” of information processing to consider the situated nature of these systems.[[518]](#footnote-519) Because the environment and its features play a crucial role in the functioning and organization of living systems, these factors are a significant component of the way living systems are considered. In contrast, Langton’s concerns were oriented toward an excessive focus on computational approaches which generate formal abstractions of life. This approach separates living beings from their physical instantiation, ignoring the embodiment of a system and its *situatedness* within an environment.[[519]](#footnote-520)

 While initially, ALife focused on computational processes enacted in simulated environments, research today involves both Langton’s and Varela’s approaches to studying life.[[520]](#footnote-521) To implement physically embodied systems, an understanding of the requisite computational processes is required; however, simulated environments are distinct from the physical world. As such, ALife research is divided into three categories: hardware, software, and “wetware” or artificial cells synthesized in a laboratory.[[521]](#footnote-522) While software approaches to ALife rely on computer simulations of cells and organisms, hardware approaches involve robots which learn to navigate and respond to their environment, as seen in the work of Rodney Brooks. His contributions to ALife would eventually become adopted by AI researchers as a way for robots to adapt to and learn about dynamic environments, leading to the development of embodied robots like iCub.[[522]](#footnote-523)

 This shift in directions for AI development also saw support from AI critic Hubert Dreyfus, particularly in his book *What Computers Can’t Do* originally published in 1972. Sceptical of the excitement and hype around symbolic-reasoning approaches to AI, Dreyfus’s first publication was a report written for the RAND Corporation in 1965 titled *Alchemy and Artificial Intelligence*.[[523]](#footnote-524) In it, he suggests that human problem-solving is not reducible to the kinds of discrete operations used in symbolic-reasoning. Furthermore, he argues that digital computers are not simulating the manner in which the brain functions but instead, are performing an entirely different kind of information processing altogether.[[524]](#footnote-525) These ideas would be further developed and explained in *What Computers Can’t Do*, where Dreyfus recommends a new approach to AI based on his study of phenomenologists like Heidegger and Merleau-Ponty.[[525]](#footnote-526) Because much of human knowledge is based on *know-how*, or “inarticulate, preconceptual background understanding of what it is like to be a human being,” any attempt at formalizing this know-how into symbolic representations appeared to be a “hopeless task.”[[526]](#footnote-527) The alternative Dreyfus suggests is one which produces machine intelligence from experience, learning, and the acquisition of skills.[[527]](#footnote-528) In *What Computers Still Can’t Do*, published in 1992,[[528]](#footnote-529) Dreyfus states that although neural networks offer a more promising approach to AI development, a new problem emerges into view.[[529]](#footnote-530) He states “One needs a learning device that shares enough human concerns and human structure to learn to generalize the way human beings do. And as improbable as it was that one could build a device that could capture our humanity in a physical symbol system, it seems at least as unlikely that one could build a device sufficiently like us to act and learn in our world.”[[530]](#footnote-531) While Dreyfus appears to see the benefit to approaching AI from a perspective rooted in embodied cognition, he seems to hint that something else might be required, something akin to “human concerns.”

 My suggestion is that this missing element consists of an analogue of emotion for machines to support a form of self-organization. This version would involve the manifestation of behaviours from experiences of pain and pleasure, along with learned associations between these sensations and the various stimuli agents encounter within the environment. As the robot establishes these associations, it organizes its behaviour around aspects of the environment and their impact on its functioning, seeking out stimuli which generate pleasure and avoiding those which cause pain. From this foundation of learned associations, a form of “inarticulate, preconceptual background understanding”[[531]](#footnote-532) could emerge, generating automatic or reflex-like responses to specific stimuli.

 At this point, it would be reasonable to inquire about the differences between hardware approaches to ALife and the development of robotics in AI, as the two domains appear to be rather similar. Though there is considerable overlap, hardware-based ALife “explicitly and extensively” applies inspiration from all forms of life, not just humans.[[532]](#footnote-533) One approach has involved the use of supercomputers to coevolve a robot’s morphology with its functional controllers, coupling its body and functionality to produce behaviours, where a three-dimensional printer subsequently builds a physical version of the robot.[[533]](#footnote-534) Another approach investigates ways for robots to continuously diagnose and repair damage to their bodies.[[534]](#footnote-535) While some AI robots may have drawn inspiration from ALife, AI approaches are generally concerned with creating functionality to bring about a specific behavioural output, like picking up objects or detecting features.[[535]](#footnote-536) Robots designed from an ALife perspective, however, would instead be designed in such a way where behaviours are generated to achieve a specific outcome *for* the machine’s needs or functioning. In living beings, if an organism is hungry, it regulates its behaviour for the sake of acquiring food, where the food intake is the input which satisfies an internal motivation to eat. Because living beings are motivated to act in order to fulfill specific goals which satisfy internal needs, robots built to mimic living systems should follow suit. A robot’s goals should focus on satisfying their own needs and desires as indicated by their perceptual systems.[[536]](#footnote-537) Likewise, if the robot’s perceptual system indicates an environment is too noisy, for example, it modifies its behaviour to reduce the amount of noise entering its auditory-processing channels.

 To overcome the limitations presented in Chapter 3.3, social robots should be developed in a manner which gives rise to experiences, particularly emotional experiences. Given the significance of experience for providing an organism with information about the physical world and its influence on its body, social robots should be built with a form of subjective experience. This would enable it to become analogously invested in its own continued functioning. Included in this requirement is an ability to feel emotions and various affective states, as emotions infuse stimuli with meaning and significance which the agent uses to act and make decisions. This aspect of biology is currently missing in current robotic applications like iCub, an omission which results in both a lack of interest in its own survival, and subsequently, a lack of understanding of words related to emotions.

 Over these last two sections, some important features of machines have been identified for recreating central aspects of living beings. With these ideas in mind, we can now analyze a new strategy and understand why it constitutes a better approach than iCub for generating social robots. Though the developer’s interest resides in machine consciousness, a topic beyond the scope of the present work, it nevertheless provides a good alternative due to its explicit appeal to theories generated from empirical evidence. Specifically, it provides a method for creating machine emotions in an analogous manner to animals, where these emotions can become associated with stimuli the robot encounters. Through this associative mechanism, a robot is able to learn about the world and the ways in which it impacts its own body and functioning, imbuing the robot with subjective experiences.

4.3 – A Candidate Solution

The new direction discussed in this section has been developed by Dr. Pentti Haikonen, the Principal Scientist on Cognitive Technology at the Nokia Research Center in Helsinki, Finland, from 1991 to 2009.[[537]](#footnote-538) His particular interest is in consciousness and its implementation in machines, where ‘consciousness’ refers to an agent’s ability to report on perceptions of stimuli from internal and external environments.[[538]](#footnote-539) Given this interest, Haikonen has deliberately added experience into his cognitive architecture. His solution uses associative learning, memory, and evocation to establish connections between incoming sensory information from signals generated by sensors on the robot body. By incorporating signals which are analogous to pain and pleasure in animals, his architecture enables the robot to determine the meaning of stimuli through how they impact its body.

 Haikonen also appeals to differences between digital computers and biological brains to argue that all meaning is ungrounded in robots governed by software running on digital computers. Although further explanation of this argument requires a lengthy discussion beyond the scope of this work, it is worth mentioning here as a significant reason for Haikonen’s motivation for creating this new architecture. For our purposes, however, we are interested in the Haikonen Cognitive Architecture (HCA) for its inclusion of emotion at a fundamental level of robotic operation.

 According to Haikonen’s perspective on cognitive machines, digital computers operating on binary representations should not be included in social robots because computers only process symbols, resulting in the *symbol grounding problem*.[[539]](#footnote-540) This problem is due to the fact that the meanings of these symbols are explained by other symbols, rather than self-explanatory information or real-world phenomena. Since symbols are explained by other symbols, the reference becomes circular and is thus uninformative and ungrounded. In digital computers, these symbols exist in the form of binary values which refer to numbers and characters like letters of an alphabet. As a device which only operates on binary values, a digital computer cannot assign a meaning to the words it receives and displays, an idea also mentionedby Varela, Thompson, and Rosch in *The Embodied Mind*.[[540]](#footnote-541) Haikonen argues that because the brain is not a computer, it does not use binary values or numeric computations to perform algorithms.[[541]](#footnote-542) Since numbers do not give rise to experiences in computers, the execution of any computer algorithm will not be sufficient to produce the experiences necessary for consciousness. As such, a robot with an ability to feel and experience the world must be built without binary representations or numbers. Even if the computer were to possess a sensor coded for pain, the pain signal itself remains a representation of a physical phenomenon in the form of binary values. In humans and animals, although the activity or functionality of individual neurons can be represented by binary values, its physiological form is of electrical signals generated by neurotransmitters, as will be discussed next. Though much more can be said on this topic, it has been introduced here for background into Haikonen’s aims in creating a new approach to robots, as explained in the second edition of *Consciousness and Robot Sentience.*

 Before discussing the specifics of this approach, it is vital to briefly discuss what neurons are and how they function. A neuron is one type of cell located in the brain and together, via the central nervous system, neurons are responsible for sending and receiving signals throughout the body.[[542]](#footnote-543) To accomplish this, a neuron *fires* and transmits trains of electric pulses, provided the amount of incoming energy from one or more neurons exceeds a specific threshold. At the beginning of this process, *dendrites*, which resemble tree branches extending outward from the neuron’s *cell body*,receive incoming signals in the form of chemical compounds called *neurotransmitters*.[[543]](#footnote-544) With sufficient stimulation from neurotransmitters, a chemical reaction occurs at the *axon hillock* located at the base of the cell body, transmitting the signal through the tail-like structure of the neuron called the *axon*. This transmission occurs from a series of electrochemical reactions to propel the signal along the axon, until it reaches the *axon terminals* and releases neurotransmitters into the *synapse*. The synapse is the space between neurons where the dendrites in the neighbouring neuron detect their presence, causing it to alter its pattern of activity if sufficiently stimulated.[[544]](#footnote-545) Though neurons maintain a base-rate of firing, the neuron itself acts in an *all-or-nothing* manner, firing at the same strength every time.[[545]](#footnote-546) Neuronal signals are thus generated when their base-rate of firing changes in response to the presence of neurotransmitters.

 There are a variety of different types of neurotransmitters. While some create an excitatory effect in the surrounding neurons, increasing their likelihood of firing, other types of neurotransmitters have an inhibitory effect.[[546]](#footnote-547) These neurotransmitters thus decrease the likelihood of the firing of adjacent neurons, playing an important role in facilitating relaxation and a decrease in arousal. An example of one such type of neurotransmitter is *gamma-amino butyric acid* (GABA), significant for both inducing sleep and promoting deeper, slow-wave periods of sleep.[[547]](#footnote-548)

 As one neuron’s firing leads to the firing of adjacent neurons, these neurons grow toward each other, leading to an increased likelihood of firing in the future.[[548]](#footnote-549) This provides a significant mechanism for learning, first discovered by Canadian neuroscientist Donald Hebb in 1949.[[549]](#footnote-550) This phenomenon has since been named Hebb’s Law or *Hebbian learning* and is often summarized by the phrase “cells that fire together wire together.”[[550]](#footnote-551) This mechanism is responsible for the associative learning observed by Ivan Pavlov in the early 1900’s in his experiments with dogs and food, as mentioned by Wiener and noted in the previous section of this chapter. Pavlov discovered that dogs would be *conditioned* or taught to salivate in response to hearing a tone, provided the same stimuli had been previously introduced as the dogs were given food.[[551]](#footnote-552) After a number of concurrent instances of presenting food with the tone, the dogs would no longer require the presence of food to begin salivating; the tone alone was sufficient. Thus, the sound became associated with being fed, initiating salivation. These experiments indicated the power of association, where two stimuli can be cognitively connected such that the presence of one stimulus evokes an association with another stimulus.[[552]](#footnote-553) Forty years later, Hebb would discover the neural mechanism responsible for association.

 Modified Hebbian learning is also responsible for machine learning in the cognitive architecture developed by Haikonen.[[553]](#footnote-554) Rather than using numerical values to perform calculations, as observed in digital computers, the Haikonen Cognitive Architecture (HCA) is controlled by an assortment of threshold levels which affect the robot’s behaviours and emotional state. Learning is established through the use of dedicated circuits representing synapses which are embedded within a larger electrical circuit called the Haikonen Associative Neuron (HAN). These associative neurons are designed to compare signal patterns generated by sensors on the robot’s body. The HAN fires when an incoming signal, the *main signal*,[[554]](#footnote-555)matches or sufficiently resembles a stored signal pattern, known as the *associative signal pattern*[[555]](#footnote-556)or *vector*.[[556]](#footnote-557) Both the main signal and associative signal pattern are comprised of a number of input signals representing *features* of a particular stimulus.[[557]](#footnote-558) Each feature within a pattern is connected to a synaptic weight circuit.[[558]](#footnote-559) For example, if an associative signal pattern consists of seven features, the HAN contains seven synaptic weight circuits. These features are determined based on a particular sensory modality, made up of parts which together, represent the qualities of the stimulus detected within the external environment. This will be explained in further detail shortly.

 Within each of these synaptic circuits, the main signal is *correlated* with the associative input signal to produce a *weight* in the form of a binary value, either 1 or 0.[[559]](#footnote-560) To do so, the main signal is multiplied by the associative input signal and the product is passed to an *accumulator* which stores a *correlation sum*, which will be compared to a preestablished threshold. If the product passed to the accumulator equals 1, the value of the correlation sum is incremented by a value of 1.5.[[560]](#footnote-561) Alternatively, if the product passed equals 0, the correlation sum is decremented by a value of 0.5. The correlation sum is then compared to the threshold value and if it exceeds the value set, a switch is closed and the synaptic weight is set to 1. Initially, prior to any learning, the weight of the synapse is set to 0 and the switch is open. When the threshold is set to a low value, learning occurs quickly since the first instance of multiplication pushes the correlation sum over the threshold. This closes the switch, setting the weight to 1. At this point, the associative signal passes through the synapse and is multiplied by the synaptic weight.

 The synaptic circuit also contains a *learn enable signal* in the form of a binary value. When set to 1, the learn enable signal is on and learning can occur when the main signal and associative signal occur at the same time. When learning is not enabled and the signal is set to 0, learning cannot occur. This aims to control the occasions in which the robot is capable of learning, mimicking attentional processes in animals and humans.[[561]](#footnote-562) If this signal were not included, new learning may conflict with previously learned information.

 Just as the brain contains neurotransmitters which inhibit the firing of adjacent neurons, an inhibitory synaptic weight circuit has been developed to mimic this functionality in Haikonen’s model. The *inhibiting neuron group* acts similarly to the GABA neurotransmitter by decreasing the likelihood of the surrounding neurons to fire.[[562]](#footnote-563) This neuron group is useful for instances which require the robot to avoid performing an activity, for example, stopping its forward movement to avoid running into an obstacle.[[563]](#footnote-564)

 Returning to the functionality of the HAN, the neuron produces four binary outputs: the output signal representing the main signal, a match signal, a mismatch signal, and a novelty signal. The output signal is determined by summing the synaptic weights and comparing this value to the HAN’s threshold. If the sum of the weights exceeds the value of the threshold, a match between the main signal and the associative signal pattern has been identified and the match value is set to 1.[[564]](#footnote-565) At this stage, the output signal and match signals are set to 1, while the mismatch and novelty signals are set to 0. A mismatch is identified when the main signal does not match the associative signal pattern and the synaptic weights do not total a value greater than the threshold. In this case, the mismatch value is set to 1 while the output signal, match, and novelty signals are set to 0. Novelty is detected when a main signal exists without a corresponding associative signal pattern, and in this case, the novelty signal is set to 1 while the other signals are set to 0.[[565]](#footnote-566)

 As mentioned above, both the main signal and associative signal patterns entering into the HAN are comprised of features which are then compared.[[566]](#footnote-567) The features of the main signal are determined by preprocessing circuits or *filters* and are separated into parts depending on the particular sensory mechanism. The robot’s architecture would contain a number of sensory modalities, all represented by different sensors, such as audio or light sensitive receptors that provide sensory information about some aspect(s) of the external environment.[[567]](#footnote-568) After the sensory information has been preprocessed by filters to detect features of stimuli, these signal vectors are passed to feedback neurons comprised of associative neuron groups to be determined whether a match, mismatch, or a novel event is present. These associative signal patterns represent the robot’s expectations or predictions based on previous learning. The stage of processing which involves the use of HANs is called the *perception/response feedback loop* as it determines the action the robot should take as an outcome of the match, mismatch, or novelty situation. Within this feedback loop, each extracted feature signal for a particular sensory module is compared to its corresponding associative signal.[[568]](#footnote-569) Once this comparison is complete, the associated signal pattern is now considered a *percept* and is subsequently fed back into the same feedback neuron group of HANs. Here, it becomes a new “virtual” percept, one which depicts an internally evoked or “imagined” entity.[[569]](#footnote-570) This percept is also broadcast to other neuron groups to become associated with other signal vectors, including ones representing distinct sensory modalities.[[570]](#footnote-571)

 To get a better sense of how this feedback loop gives rise to robot behaviours, an overview of the core sensory modalities is necessary. Mimicking animals and humans, the robot’s cognitive architecture includes inputs for audio, visual signals, haptic information for a sense of touch, kinesthetic information about the robot’s body, as well as specific sensors for representing pain and pleasure. Each sensory modality contains its own perception/response feedback loop, and these are cross-connected for learning and governing the robot’s general behaviour.[[571]](#footnote-572) The framework which constitutes the robot’s “brain” is called the Haikonen Cognitive Architecture (HCA).[[572]](#footnote-573) Interestingly, while the HCA aims to recreate human abilities, Haikonen notes this architecture could be altered to include additional sensory modalities absent in humans, including the sensing of electric, magnetic, or electromagnetic fields.[[573]](#footnote-574) That said, as it exists currently, each modality will now described in further detail.

 The HCA supports the use of one or more microphones[[574]](#footnote-575) for detecting sounds in the environment. Incoming audio signals are first processed by a set of filters which perform frequency analysis by separating and isolating individual frequencies of a sound,[[575]](#footnote-576) as well as the direction they are coming from.[[576]](#footnote-577) Additionally, the temporal durations and the rhythms of sounds are also learned by associative neuron groups,[[577]](#footnote-578) where a circuit dedicated to autoassociative memory supports both prediction and the instant replay of sounds.[[578]](#footnote-579)

 For vision, the HCA captures and processes light through the use of hardware such as a digital cameras or photodiode sensors. Digital cameras can be used to create a two-dimensional array of *pixels* or picture elements which are assigned a numerical value proportional to the intensity of illumination.[[579]](#footnote-580) For this pixel map, higher values indicate a higher amount of light present within that area of the image. Colour values are indicated by three additional pixel maps, one for each primary colour of light: blue, green, and red. To detect other visual features of an image, additional pixel maps are required, for example, pixel maps indicating line features, temporal changes, and motion.[[580]](#footnote-581) Alternatively, the HCA could use two photodiodes which produce an electrical current from the absorption of photons.[[581]](#footnote-582) The image of the target is projected on to the photodiodes through small lenses, and due to the parallax effect, the movement and direction of the target can be inferred from the relative amplitude of the electrical signals.[[582]](#footnote-583) These output signals are then used to direct the motor actions of the robot, either approaching the target or avoiding it, depending on the robot’s learning and the nature of the target.[[583]](#footnote-584)

 The actions performed by a robot utilizing the HCA depend on its inner state which is influenced by feelings and associations related to pain or pleasure.[[584]](#footnote-585) The robot’s “shock sensor” consists of a small magnetic earphone and is sensitive to vibrations within its body.[[585]](#footnote-586) This sensor indicates the presence of a stimuli capable of causing damage to the robot, sending signals to the displeasure neuron group.[[586]](#footnote-587) For pleasure, a separate “petting sensor” registers a touch and sends signals to a pleasure neuron group, acting as an intrinsic reward to reinforce behaviours.[[587]](#footnote-588) Stimuli associated with rewards teach the robot to approach and further interact with the source of pleasure. On the other hand, stimuli associated with pain lead to situations of avoidance to reduce the negative impact the stimuli has on the robot itself. These pleasure and pain signals can also be associated with words like ‘good’ or ‘bad’, such that when these learned words are paired with specific stimuli, the robot can learn which stimuli to avoid and which to approach.[[588]](#footnote-589) From these elementary signals related to pleasure and pain, the robot is able to develop its own versions of emotions, as suggested by Haikonen’s Systems Reaction Theory of Emotions (SRTE).[[589]](#footnote-590) This theory suggests that robot cognition and behaviours are predicated on its reaction to stimuli in the environment. An emotional evaluation of a stimuli initiates cognitive processes for performing actions, in addition to generating reactions and percepts about the stimuli itself. Machine emotions are created from combinations of machine sensations analogous to pain and pleasure in animals, along with other features of cognitive processing, such as mismatch and novelty.[[590]](#footnote-591) For example, machine sadness is comprised of sensory mismatch and strong pain signals, while machine surprise follows from a sudden and large degree of mismatch.[[591]](#footnote-592)

 The robot’s body also contains sensors related to its own movements and positions, along with perception/response feedback loops for comparing expected information to information actually captured from the environment. Sensors for kinesthetic information about the robot’s body indicate its direction of movement and the robot’s position within a space.[[592]](#footnote-593) The robot is able to alter its movements and behaviours as a result of the match, mismatch, and novelty outcomes from feedback processes. Kinesthetic sensors are also used to produce information about the direction of the robot’s gaze, allowing it to adjust its own position to better track objects and their movement.[[593]](#footnote-594) Haptic feedback representing the robot’s sense of touch is provided by sensors in its gripper “hand” to let the robot know when it has grasped an object.[[594]](#footnote-595) The percepts generated from haptic processing also support the sensations of different shapes, textures, as well as the hardness or softness of an object. Haptic feedback is combined with kinesthetic and visual feedback to explore the properties of objects, where sensors on the robot’s body provide information about the object it is interacting with.[[595]](#footnote-596)

 The HCA and the various sensory modalities which contribute to the robot’s abilities and functionality are separated into *modules*. Each module is responsible for processes related to specific elements of the robot’s functionality, where modules 1 and 2 specialize in motivations related to survival.[[596]](#footnote-597) Specifically, module 1 contains the feedback loops for pain and pleasure, determining what should be considered “good” and “bad” to the robot based on learning about the effects of stimuli.[[597]](#footnote-598) Module 2 focuses on information related to the robot’s physical requirements, including sensors for its energy levels, motor drive levels, its temperature, balance, mechanical tension, among others.[[598]](#footnote-599) The sensors in this module may send pain information to the first module to motivate certain actions. Module 3 includes haptic information and is related to self-image and sensing the environment, while module 4 includes information about the environment by interpreting visual data. Module 5 also captures information about the environment but through auditory processing, and it is in this module that speech and language are also processed.[[599]](#footnote-600) The robot’s direction and orientation is processed in module 6, while module 7 involves kinesthetic processing for the generation of motion and motor activities through percepts generated by other modules.[[600]](#footnote-601) Each of these modules is capable of communicating with other modules, where percepts generated from feedback loops within each module are broadcast to other modules.[[601]](#footnote-602) By generating more complex and multilayered associations between percepts from distinct modules, the robot is able to learn about its environment and how aspects of the physical world impact its own being and functionality. The fundamental role of pain and pleasure influence the robot’s own internal motivations by informing it about which objects or environmental aspects should be approached and explored further, and which are to be avoided.[[602]](#footnote-603) In this way, the decisions the robot makes are influenced by information related to affect and emotion,[[603]](#footnote-604) just as observed in humans and animals given the research findings made by Antonio Damasio[[604]](#footnote-605) as mentioned in the previous chapter.

 By using the associative signal patterns from each module’s set of feedback loops, the robot is capable of internally evoking percepts associated with a particular cue.[[605]](#footnote-606) For example, if the robot learns that the word ‘cat’ is associated with a particular animal, speaking the word “cat” evokes an internal or “virtual” percept of the image it has associated with the word. This internally generated percept is created by its various feedback loops, as learned associations can evoke percepts upon registering an associated cue, such as a spoken word or visual image of an item. This functionality mimics inner imagery and inner speech in humans, as the robot can “imagine” or internally evoke a stimulus from the presence of associated cues. The evocation of the robot’s inner speech or inner imagery would present the percept in a similar way to how it appears in humans, where some features of the percept are less vivid or missing altogether if they cannot be recalled.[[606]](#footnote-607) Returning to the cat example, the details of the cat’s colouring may not be as clear in an imagined percept, however, the general body shape of the cat may be fully recalled.

 Associations can be stored in memory through the use of Accept-and-Hold (AH) circuits, which separately store the signal vectors of percepts broadcast from perception/response feedback loops.[[607]](#footnote-608) Each AH circuit stores one signal vector, where multiple signal vectors are then cross-associated with others within an associative neuron group. Here, the associative neuron group links percepts together such that one percept acts as a cue to retrieve information associated with it, in a cross-referential manner. An example to further illustrate this structure involves an item left in specific locations at certain times;[[608]](#footnote-609) after coming home from work, a cellphone is plugged in to charge in the kitchen, and after dinner, the phone is moved to the living room. Recalling where the phone is located can be cued by the time of day as, prior to dinner, the phone is in the kitchen, while afterwards, the phone is in the living room. The cross-associations generated within the associative neuron group generate synaptic weights and act as memory traces for the two scenarios of described above. Match, mismatch, and novelty outcomes also arise from this associative neuron group, indicating instances where a set of percepts are either associated with each other or are not.[[609]](#footnote-610) For example, a mismatch would occur if an incoming set of signals contained vectors representing ‘cellphone’, “before dinner,” and ‘hallway’.

 This version of memory formation is similar to the creation of short-term memories in people, where recent situations can be recalled for a limited period of time before they are forgotten.[[610]](#footnote-611) The HCA is also capable of storing long-term memories for situations characterized by high emotional significance. Alternatively, long-term memories can be formed when information is circulated within perception/response feedback loops and is subsequently recalled by short-term memory to be memorized again.[[611]](#footnote-612) In the case of emotionally-charged memories, the threshold for association in the HAN is lowered such that an instantaneous association can be made.[[612]](#footnote-613) For circulated memories, a separate long-term neuron group receives signal vectors which enter into short-term memory circuits. This performs the same cross-association seen elsewhere in the HCA, albeit with lower HAN thresholds. Thus, a higher number of repeated associations between incoming signal vectors is necessary for the association of stimuli. Recall is performed in the same manner in long-term neuron groups as short-term neuron groups, such that the presentation of a stimulus cues associated percepts to be remembered.

 It is through these learned associations in the robot that meaning can be understood and language can be acquired. The associative neuron groups within the perception/response feedback loops enable the transition from sub-symbolic processing to symbolic processing, where the main signal vector acts as a symbol for the corresponding associative pattern.[[613]](#footnote-614) The associative signal patterns within the feedback loops used for comparison against the incoming main signal consist of the sub-symbolic features which represent a stimulus. For example, sub-symbolic features of visual stimuli may include shapes, colours, and textures. Items are identified based on how an incoming signal compares to expectations and predictions. For example, a cellphone is generally rectangular and thin, and when the screen is off, is black and somewhat reflective of light. The visual information representing a cellphone can be associated with the spoken word ‘cellphone’, where hearing the word evokes the associated visual signal pattern which represents the object.[[614]](#footnote-615) The association between these two stimuli grounds the meaning of the word ‘cellphone’, as the sub-symbolic information generated from sense data are combined to create an understanding of what the symbol ‘cellphone’ refers to.[[615]](#footnote-616)

 Because robot emotions also arise from internally-generated percepts from sensors on the robot’s body, it is able to ground the meaning of words like ‘pleasure’ and ‘sadness’ in a similar manner. The sub-symbolic information generated from its “petting sensor” becomes the referent of the word ‘pleasure’ and similar terms like ‘joy’ or ‘comfort’. When sub-symbolic information is combined with other sub-symbolic information from system reactions, more complex robot emotions or affective states can be created.[[616]](#footnote-617) If the robot associates the word ‘good’ with pleasure signals from the “petting sensor,” and subsequently the word ‘good’ with ‘cellphone’, a desire for interacting with a cellphone can be learned.[[617]](#footnote-618) Alternatively, ‘sadness’ can be grounded in a combination of pain sensations and sensory mismatch, where an expectation for something good like a cellphone is taken away as the robot’s body is being struck. When the robot is in this mood as a result of its experiences, the utterance of ‘sadness’ can be learned over time through the repetition of this scenario. Therefore, the robot understands what words like ‘sadness’ and ‘pleasure’ mean, as the referents of these words are grounded in the robot’s own sensations and subjective experience.

 From this grounding of words and meaning, language can be generated through *vertical* and *horizontal grounding*. Vertical grounding involves the association of sensory information and percepts to words, as seen in the previous examples regarding emotions. Adjectives like ‘square’ and ‘black’ can be determined through correlative learning, where repeated interactions involving different objects sharing the same characteristic indicate the feature being referred to.[[618]](#footnote-619) Horizontal grounding, on the other hand, associates the words within a sentence or multiple sentences to one another.[[619]](#footnote-620) Just as objects, locations, and times of day can become associated to form a memory of where an item was left after dinner, the parts of a sentence can also become associated with one another. For example, the sentences “the cellphone is good” and “the cellphone is black and rectangular” associates ‘cellphone’ with the adjectives ‘good’, ‘black’, and ‘rectangular’. When horizontal grounding and vertical grounding are combined, the system is able to report its experiences through language based on the associations it has learned.[[620]](#footnote-621) Moreover, linguistic syntax can be learned by associating elements of sentences together, like word order and tense. Additionally, vocal inflection or the use of punctuation can also be learned through association.[[621]](#footnote-622) Asking the robot “what is black and rectangular?” will generate the answer “cellphone” provided the associations have been learned, and upon querying the robot about whether the cellphone is bad, the answer will be “no.”

 The HCA also supports robot speech by imitating the sounds and words the robot hears.[[622]](#footnote-623) To accomplish this, sound features processed by the auditory feedback loop are forwarded to a *sequence neuron assembly* which acts as a temporary memory store with instantaneous learning.[[623]](#footnote-624) The reason for this store is to collect and remember auditory information as it is being heard, only repeating sounds and words after the person speaking has finished.[[624]](#footnote-625) Auditory percepts are then passed to a kinesthetic perception/response feedback loop which imitates the detected temporal signal patterns.[[625]](#footnote-626) Speech sounds can be produced by synthesizing various sounds to generate a wider, more flexible range of sounds and words.[[626]](#footnote-627) Signals are subsequently forwarded to hardware like an audio amplifier and loudspeaker, where the output sound is captured by the robot’s own auditory processing channels. Initially, this is the only way in which the robot can hear its own inner speech. Over time however, an internal feedback loop can emerge, allowing the inner speech to be heard as silent speech without the need to talk aloud. Subsequent rehearsal of these words and sounds from reentrant auditory processing allows the robot to permanently learn the words it is exposed to.[[627]](#footnote-628) Moreover, the established connection between perceived sounds and output signals is able to cause the robot to mimic the sounds it hears in the environment, acting similar to the so-called mirror neuron activity discussed in Chapter 2, albeit without the use of any specific or unique “mirror neurons.”[[628]](#footnote-629) Through the generation of associations between heard words and spoken sounds, in conjunction with the vertical and horizontal grounding of language, the HCA supports language acquisition. This enables the robot to both understand phrases and produce linguistic responses.

 A functional prototype of a robot using HCA and HANs can be viewed in demonstration videos uploaded by Dr. Haikonen to his YouTube channel.[[629]](#footnote-630) In these videos, the prototype robot XCR-1 exhibits an ability to learn its own name and respond to being called.[[630]](#footnote-631) The robot can also learn to avoid objects which have been previously associated with pain signals, as the robot associates an object with the sensation of its body being struck.[[631]](#footnote-632) Moreover, the associative processing also enables the robot to recognize itself in a mirror since it learns the connection between visual stimuli detected from the mirror and its own kinesthetic activity.[[632]](#footnote-633) These videos demonstrate the ways in which associative neurons are able to generate appropriate behaviours to various stimuli, mimicking the way animals and humans react and respond to aspects of their environment.

 Therefore, Haikonen’s approach indicates a promising direction for overcoming limitations for social robots. Since language and empathy depend on capacities which cannot be replicated in existing robots like iCub. The reason this architecture is suitable is because it follows processes identified in living beings and aims to recreate these processes in a machine. Haikonen’s SRTE is a good model for machine emotions because reflects physiological regularities observed in nature. The resulting combinations of robot experiences provide a model which supports a rudimentary foundation for empathy in machines. Moreover, these feelings are comprised of electrical signals which are generated by the body to establish associations between stimuli, where these associations provide a sense of meaning for the robot. As such, its “mind” and behaviour is *for* the body to keep the system operating, as observed in animals and humans. This enables the agent to ground the meanings of emotions, as the robot has been constructed to generate its understanding of the world from specific sensors on its body related to pain and pleasure.Though XCR-1 is a simplistic model for the purposes of showing a functioning proof-of-concept, this approach can be expanded upon such that the robot is able to learn more words and objects. This would eventually enable the robot to produce sentences reflecting its own experiences operating in its environment.

 Further development of this approach would generate a robotic analogue of empathy since a capacity to imitate is already present even in its current iteration. Due to XCR-1 being able to understand basic pain and pleasure, with further training, the robot could associate its own feelings with the detection of emotional states in others. If the robot were to learn to feel distress upon detecting distress in others, it could become motivated to alleviate its own negative feelings through attending to and comforting others, as witnessed in some animals. Since an act of empathy arises from an interaction between two agents, the robot would leverage various behavioural cues to act appropriately, modifying its behaviour in response to the match, mismatch, or novelty signals produced from internal feedback loops. Since it is capable of experiencing inner states, the robot’s act of empathy is not a mere simulation but a recreation of the processes involved in human and animal empathy.

 Therefore, for more lifelike social human-robot interactions, a new approach to developing robotics is required. The previous chapter established the limitations of existing AIs like iCub, and in response, this chapter has offered an alternative and appealing solution. The reason for adopting Dr. Haikonen’s approach for the development of social robots is due to its ability to generate internal sensations from bodily sensors, and from these sensations, cognition and behaviour responds to environmental stimuli. This is in contrast to current AIs which generate behaviours without the use of internal sensations and experiences. While some robotic applications can make do with this approach, social robots are better off if they are able to feel and experience the world like humans and animals. The architecture invented by Dr. Haikonen also better mimics biological regularities as it makes use of feedback loops for machine learning and the regulation of behaviours. By basing behavioural outcomes on the robot’s own physical experiences, it is able to operate in a way more analogous to humans and animals, leading to better artificial agents for socializing with people.

 Altogether, this chapter aims to illustrate the rationale for a new approach to building AIs given the shortcomings identified in the previous chapter. Specifically, machine behaviour is generated by the way signals generated by bodily sensors influence its own interests, as indicated by the presence of analogues of pain and pleasure. These sensations not only give rise to analogous affective states, a requirement for empathy, but they also provide the machine with the meanings of the stimuli it encounters. An object associated with analogous pain signals is deemed “bad” given its impact on the machine’s functioning. This gives rise to behaviours which aim to mitigate the stimulus’s effects to promote its own continued functioning. In this manner, the robot is able to organize its own functionality around its experiences with the environment, demonstrating a similarity to the self-organizing processes central to biological organisms. Without these analogous affective states, environmental stimuli and aspects of the wider world are meaningless, as the robot has no stake in its own survival as an autonomous system. The rudimentary self-organizing behaviours observed in the robot XCR-1 arise from feedback loops, where Haikonen Associative Neurons are used to process and reprocess percepts for the sake of governing its behaviour according to the demands of the environment. Although affective states and emotions in humans and animals are often considered reactions or responses to interactions between agents and aspects of the world, their valence provides vital information about the environment. This information pertains to the individual’s survival and point of view as a living being as it navigates the world. Decision-making without this underlying emotional framework in animals like humans is not feasible nor desirable, as it overlooks an integral element of *evaluation*. This evaluation occurs from the ways in which stimuli give rise to affect and emotional experiences, where stimuli are evaluated as ‘bad’ if they negatively impact the individual. While computers and other machines may not require the implementation of analogous affective states to perform behaviours, any true attempt at recreating human reasoning arguably does. Given that computers are incapable of having experiences, our current attempts at creating “artificialintelligence”are not as well-informed as they could be. By building a machine with the capacity to experience its own form of emotions and affective states, it could understand for itself what emotions and feelings mean to humans.

 The following chapter concludes this work by integrating the discussions presented throughout these four chapters to present a response to Stevan Harnad’s quote about robot behaviour. The goal of this work is to demonstrate the importance of developing affect for empathy in social robots, as empathy has been identified as a significant characteristic for social robots. This involves communication with a degree of social appropriateness and emotional sensitivity, one learned through interacting with a myriad of different individuals from different backgrounds. To accomplish this, the robot must be able to experience the world in an analogous manner to humans and animals. Any social robot without this understanding of emotion consists of a mere simulation, potentially introducing harms to human lives and societies. Until these experiences are implemented, it is insufficient to conclude that the robot acts with empathy simply because it is behaving as if it does.

Chapter 5 – Concluding Remarks

 After reviewing the contents of the past four chapters, we return to investigate a particular quote by Stevan Harnad regarding robot minds. Given the fundamental differences between living organisms and man-made machines, the conclusion that we can treat robots as if they had a mind of their own is unjustifiable. To do so would lead to further confusion regarding robots and their behaviours, introducing potential risks of harm to humans. Individuals may feel deceived or betrayed by robots sold as social companions, potentially leading to an increased sense of loneliness.

5.1 – Summarizing the Argument

We live in a world excited by the prospect of new machines capable of humanlike abilities. With recent advances in artificial intelligence and robotics, it seems that just about all aspects of human life could one day be outsourced or augmented by new technologies. In some cases, this phenomenon is partially driven by necessity. As identified in the first chapter, aging populations in societies around the world require novel solutions to meet growing demand for care and services. One approach includes using robots for support in eldercare, a solution which emerged from Japan given their status as a world-leader in both robotics development and aging populations. As time has progressed, however, more regions around the world are witnessing similar demographic trends, indicating an increasing need for elderly care. With fewer working-age adults able to meet this demand worldwide, technological solutions provide a means to assist in caring for aging individuals.

 This approach introduces questions surrounding what care involves. While robots and AI can be used in a variety of ways to assist human workers in caring for the elderly, some forms of work will require social skills and empathy. Patients must be treated with respect as individuals and not as tasks to be dealt with. Even in non-healthcare related settings, surveys indicate that people want social robots to act with empathy, expecting them to act sufficiently humanlike as to be easy and intuitive to interact with. It turns out, as demonstrated in Chapter 3, that this requirement is no easy feat. In fact, if we want our robots to act with empathy, a new approach to robotics is required.

 Human interactions are complex, and in order to discuss empathy in general, a closer look at interpersonal communications and social behaviour is required. Not only does language involve the use of syntax and vocabulary, it also relies on reference to and interaction with aspects of the physical world. Additionally, human communication uses of behaviours like body language and non-linguistic vocalizations to convey information. Social robots must be able to understand the meanings of these communicative actions to act appropriately, along with acting in a similarly humanlike manner. If robots fail to meet these expectations, confusion or disappointment will impact their wide-spread implementation and adoption.

 Even if social robots were one day able to communicate in a humanlike manner, critics like Johanna Seibt remind us that these acts would still be simulations. Her position stems from a view of social interactions as based on joint attention and reciprocation, inherent human capacities which develop over childhood. Robots, she argues, merely simulate these capacities and actions due to their fundamental differences with humans. Her perspective, introduced in Chapter 1, prompts further discussion about the simulation of behaviours, particularly surrounding empathy. As empathy requires the ability to place oneself in the perspective of another, a simulation fails to accomplish this and as such, is not a true act of empathy. Behaviours exhibited by robots do not manifest as a consequence of subjective experiences, as they are in humans and animals, but instead, appear as a result of their programming. The unfeeling robot merely acts out an emotional state, and because it doesn’t have its own perspective of the world, it cannot adopt the perspective of another.

 Empathy is an important capacity to consider in relation to social robots given its requirement in socialization and healthcare. The ability to adopt the perspective of another, to some degree at least, is a significant aspect of human life, providing a means for understanding and relating to others. Given the general aim of healthcare to reduce the suffering of individuals, empathy and respect is of utmost importance, especially with respect to nursing for patient recovery.[[633]](#footnote-634) Since we generally all know what it feels like to suffer, most people are interested in doing what they can to assist others in feeling better. In fact, researchers[[634]](#footnote-635) suggest that the motivation to assist others is directed by an individual’s own ability to comprehend and feel the sensations witnessed in the behaviours of others. In Chapter 2, after discussing the philosophical background of empathy, an empirical theory of empathy was presented which suggests that in human and some mammals, a desire to assist others is driven by the presence of an emotional contagion. Upon seeing another suffering, some animals and many humans begin to feel a degree of stress or discomfort which motivates them to address this suffering in some way.

 Although empathy involves an ability to simulate within oneself the perceived experiences of others, acts of empathy cannot be reduced to simulation alone. In some situations, efforts to simulate the experiences of others must be expanded upon by using one’s own knowledge to better understand how another is feeling. Cultural differences between individuals may complicate one’s ability to empathize if emotional display rules and customs are sufficiently distinct, as one may be unsure of the complete context of another’s experiences. As such, by appealing to one’s own knowledge of the individual in question or other information like cultural differences, individuals may better understand how another is feeling when simulation alone is insufficient.

 In this way, empathy involves an interaction between two or more people, a theory of mind proposed by Shaun Gallagher. Specific situations involving unique individuals in a variety of roles and relationships ultimately dictate whether empathy can be expressed, and whether these acts are accurate given the situation at hand. If the context and individuals involved within a particular situation is somewhat familiar, perhaps involving friends or family members, an act of empathy is more likely to be accurate. In cases where individuals are strangers to each other, it is more likely that acts of empathy may not be accurately understood, as the behaviours of others may be misinterpreted due to personal differences or other contextual factors. Gallagher’s *interaction theory of mind* provides a good explanation of empathy given its sensitivity to a variety of considerations, factors which are able to explain why acts of empathy fail or succeed. Specifically, this theory characterizes an act of empathy as emerging from the second-person perspective, a subjective point of view which is oriented outward and toward another person in an attempt to understand, communicate, or interact with them.[[635]](#footnote-636) Rather than focusing on one’s own experiences from a first-person point of view, a second-person perspective aims to establish an intersubjective understanding of the world for the sake of communication.[[636]](#footnote-637)

 Because empathy relies on an understanding of the internal states of others, it inherently deals with interpreting behavioural cues which signal emotional states. This poses a problem for social robots because emotions are produced by the body as an outcome of biology, generated through both evolutionary and developmental processes. Since current approaches to social robots involve the use of embodied computers, robots are not provided with a suitable analogue for human emotion. This was demonstrated by reviewing the world-leading developmental robot iCub in Chapter 3. Any information iCub learns about human emotion is provided to it by humans, rather than from its own body. Moreover, iCub and similar robots do not experience the world and its elements, they merely react in response to inputs and data. In contrast, living organisms interact with aspects of their environment based on the ways in which these aspects impact their bodies, resulting in emotions which signal the impact or significance of these aspects. Without experiencing for itself what emotions are, or what they refer to, the robot is unable to determine what a human means by ‘happiness’ or ‘sadness’. This lack of understanding indicates that any act of apparent empathy from iCub is a simulation rather than a machine analogue of the real capacity.

 Despite AI developers building embodied machines capable of learning through interactions with the environment, these robots are insufficiently embodied. These robots do not recreate emotions and other affective states through their bodies, as animals and humans do. Sensations of pain, for example, do not emerge in developmental robots like iCub. As such, the concept of pain cannot be understood by robots like iCub because this understanding relies on subjective experience of it. iCub may be able to recognize human emotions, yet this functionality is treated like a module to be added or removed depending on the robot’s use, rather than a core feature of the robot’s body as an agent. Instead of serving as a fundamental mechanism for learning and guiding behaviour, affect and emotion seem to be considered as just another element in a suite of computational abilities. This design decision results in an insufficiency in the way robot bodies are created, as a significant aspect of embodiment for living creatures is absent.

 This idea of embodiment is derived from a form of organization observed in living beings, namely in the form of autopoiesis or self-organization. As nested levels of physical systems, organisms are able to remain alive and reproduce as a product of the physiological interactions which comprise its body and behaviours. Subjective experiences and emotions emerged as a result of evolutionary processes because they facilitate these self-organizing processes, such as signalling damage in the form of pain. Without subjective experiences, individuals would not be able to respond to changes in the environment, and as a result, would be more likely to perish. Any awareness or responsivity observed in living organisms exists for the sake of maintaining these self-organizing processes. In fact, when Hubert Dreyfus hints at a missing element within AI, it is exactly this inherent interest or “concern” which robots do not share with living beings.[[637]](#footnote-638) Although a robot may be embodied and capable of learning over time, it does not experience its interactions with aspects of the environment, unlike biological organisms. The learning which occurs is distinct from the learning which occurs in animals because it does not arise from subjective experience, but from the modification of numerical weights within its neural networks. Though these adjustments produce changes in behaviour, the robot’s actions are not motivated by subjective experience. Instead, they result from the way its programming has been developed for a particular purpose or specification, rather than being driven by its own self-organizing processes. Even if the machine’s purpose were to be a self-governing autonomous agent, its functional design nonetheless remains fundamentally distinct from the functional organization of biological organisms.

 For robots to feel emotions in an analogous manner to humans and animals, a new approach to robotics is required. The solution proposed by Dr. Haikonen offers a better biological model of neurons as it does not use numerical values, but operates on direct percepts generated by dedicated sensors. This includes specific signals representing pain and pleasure which serve to disrupt or soothe the robot’s internal state. Moreover, these percepts are self-explanatory, providing a direct source of meaning about stimuli sensed in the environment. As a result, they can serve as symbols when associated with other percepts; for example, the association between a spoken word and visual information generates an understanding of a name for the detected object or feature. The learning which occurs in the Haikonen Cognitive Architecture is unlike the learning which occurs in existing robots, as it does not use numerical values, but direct experiences of stimuli in the environment. When stimuli are associated with pain signals, for example, they are deemed “bad” as a consequence of the ways in which they impact the body and appear within subjective experience. As a result, this causes the robot to avoid further engagement with the stimulus.

 Therefore, this new approach provides a better candidate for developing robot empathy because it mimics the biological processes which provide meaning to humans and animals. Although robots of the future would not be able to know what it is like for a *human* to experience pain, it could use its own understanding and experiences to infer how a person feels pain. With the meaning of emotions grounded in bodily perceptions, an analogue of robot empathy can be generated if the robot learns associations between behavioural cues and associated subjective experiences.

5.2 – Harnad’s Suggestion of Robot Minds

In Chapter 3, the first section discussed the history of AI and introduced the Turing Test and the Total Turing Test (TTT) developed by Stevan Harnad. Within Harnad’s paper which introduces the TTT, he states: “if our only basis for judging that other people have minds is that they behave indistinguishably from ourselves, then there’s no ground for withholding the same benefit of the doubt from robots.”[[638]](#footnote-639) Having discussed the limitations of iCub with respect to emotion and empathy, we can now clarify why this is a hazardous suggestion and an erroneous conclusion.

 From the discussion on living organisms and autopoiesis in Chapter 4, it is apparent that behaviour and the systems which govern it have emerged as a result of selective processes. Behaviours which improve the chances of an organism’s ability to survive and reproduce were selected for, causing the responsible mechanisms to potentially be passed onto its offspring. Driven by internal sensations of environmental stimuli, these behaviours generally assist in the organism’s ability to find the resources it requires to continue living. Thus, subjectivity provided a significant role in an organism’s ability to survive and reproduce. Without an ability to detect the presence of food or harm, the agent is more likely to die, as its various systems which support self-organization will cease to function. The minds of animals and humans are thus the result of physiological activity which emerged for the sake of the individual, unlike computers and robots. In robots like iCub, we cannot conclude it has a mind merely because it performs behaviours which appear to resemble those of living organisms. Minds emerged as an outcome of evolutionary development for autopoiesis; robots and computers do not have minds in virtue of their physical and functional constitution.

 Contrary to Harnad’s claim, there is plenty of evidence for withholding the assumption that existing robots have minds. With respect to other humans, and even some animals, we can safely assume these agents do have minds due to their existence as complex biological beings. Chapter 2 articulates how the human ability to perceive the minds of others results from our social tendencies, developed over evolutionary history and through childhood learning. An ability to cooperate with others and work toward shared goals provides a means for safety and security to groups of organisms, whether in searching for food or in defending territory. As such, humans and other animals slowly gained capacities which facilitate social living, such as a theory of mind. It is this biological background which allows one to assume other living creatures possess minds, depending on similarities to ourselves. Robots and other artifacts do not share common ancestors with humans and animals, and as such, cannot be said to have minds until the burden of proof has been established. Even if an analogue of a mind can be theoretically built into machines, it would remain distinct from those present in living beings. Rather than resulting from autopoiesis and evolution, it instead arises from allopoietic processes, where mechanisms external to the agent are necessary for its creation. As passive objects, robots mimicking living beings are only a simulation. A machine’s interest in the external world must be intentionally incorporated through human design, and does not inherently exist within its functionality for its own benefit. Biological organisms, alternatively, are invested in meeting the demands placed on them by the environment, behaving in ways which promote their own needs or interests. Overall, when considering whether a specific robot contains an analogue of a mind, its functional design should be considered. Embodiment must be developed in a manner which aims to recreate autopoiesis, where behaviours and cognition aim to meet environmental demands.

 The adverse consequences of assuming the presence of minds in artifacts which do not possess them are potentially vast and have the ability to affect the lives of both individuals and societies. Ascribing a capacity for agency to machines which do not possess the requisite mechanisms waives human responsibility and liability for our creations and their effects in the world. Behind all robots and computers are human decisions and practices which give rise to the actions and abilities these technologies possess; we are the causal forces behind these artifacts, not the artifacts themselves. To suggest otherwise is to abdicate responsibility for our products and their impact on others, a road which must not be taken, insofar as it leaves those suffering from the consequences unable to seek accountability. In these cases, perpetrators are allowed to carry on introducing harms to others, and victims are left without recourse. The avoidance of introducing foreseeable harms upon human populations is a motivating factor in this entire project.

5.3 – A Future with Social Robots

A conclusion drawn throughout this work stresses the deep discontinuity between humans as social, biological beings and the advent of social robots. These technologies and human activity alike carry the capacity to gravely impact human lives, we must continually investigate the ways in which these hazards can emerge. One of these ways is epistemically, where a robot’s behaviours cause people to believe they possess capacities which are absent in reality. Our social needs introduce a degree of risk not seen prior to the advent of AI. Recall the “therapist” AI named ELIZA, a text-based program which, even in the 1960’s, was capable of eliciting emotional responses from its users. Given the human tendency to anthropomorphize objects, people may become reliant on social robots for mitigating feelings of loneliness. This reliance would likely only continue to grow, for both individuals and populations, as social robots become more sophisticated and convincingly lifelike over time. Unmet expectations of social robots can cause emotional and psychological harm when erroneous feelings of attachment form, as the AI is unable to reciprocate the feeling. A danger is introduced by the idea of a *social* artificial agent, given our general assumptions and experiences with social beings like humans and some animals. Given that social interactions involve reciprocity and shared experiences, a person interacting with a sufficiently convincing social robot may assume that the agent is similar to other social beings. In reality, this is not the case, as current AIs do not experience the world to any degree. As a simulation, the individual interacting with it may develop false beliefs about the agent’s capacities, potentially leading to negative experiences such as feeling betrayed and an increased sense of loneliness. Emotional attachments to objects founded on deception or mistaken beliefs generates a source of suffering which could have been avoided by a better understanding of AI capacities.

 As populations continue to age, and with fewer working-age adults to care for them, we must be cognizant of when and how we are outsourcing human labour to machines. Though these tasks exist in the form of physical labour, as assistance with basic endeavours such as cooking and cleaning, they also exist in the form of emotional labour. Our general reliance on others to feel wanted and cared for requires us all to act with patience and compassion, especially in our fast-paced modern world. Since elderly individuals do not contribute to economies in the same manner as working-age adults, it can become easy to overlook their needs and contributions as social beings. While some daily duties or functions may be better-suited to being performed by robots and technological solutions, other aspects of life such as establishing emotional connections are best provided by a caring person.

 In addition to an increase in elderly individuals requiring care, there is also a linked and worrying rise in rates of loneliness. As a result, a greater number of people may feel compelled to turn to artificial means for company and emotional connection, a phenomenon which has already begun.[[639]](#footnote-640) Given our impressive ability to anthropomorphize objects and natural phenomena, we are at risk of ascribing to robots abilities they do not possess, generating false beliefs as a result. When these beliefs severely deviate from reality, a degree of emotional, mental, and potentially physical harm can be introduced. Social robots merely simulate behaviours identified in humans and animals, and thus cannot understand what it means to be friends or romantic partners to people. Given the existence of market expectations and pressures to deliver on these outcomes via technological solutions, it may become harder to remember this as social robots improve, especially when combined with advertising campaigns which aim to convince us otherwise.

 Even if future social robots were to be made using the Haikonen Cognitive Architecture, and one day became rather complex and highly skilled, it is vital to remember that these machines remain as human artifacts. As allopoietic machines, they are created by human means, whether through our direct efforts or through the use of other machines created by humans, and are not physically created by their own inherent processes. Although these machines would be analogous to living beings, the robot as an object remains reliant on human intervention; for example, the electricity used for its power source must be provided to it through human means. The behaviour it exhibits would arise from self-organizing processes, but the robot as a physical agent remains as an artifact built and maintained through human assistance. As a result, even if a sophisticated social robot were to be developed which could meet our social needs to some degree, their physical distinction as artifacts excludes them from fully replacing humans and animals as companions. As we have evolved to generally enjoy and require the company and care of other living beings, whether they be family members, friends or animals, AIs are too physically distinct to meet these inherent human needs. For some individuals, they may suffice in some circumstances, however, any apparent sociality remains a simulation or an analogue at best. Though they may mimic or implement some degree of self-organization, their continued functioning requires human involvement, such as in the form of repairs or energy procurement, for example. The machines we are capable of creating, at least for the foreseeable future, require our involvement for their continued operation. Otherwise, they fail and become unresponsive to environmental changes. Though they may mimic autonomous agents, they do not fully qualify as such given their reliance on human activity for their continued operation.

 Given this, we must be abundantly careful about not associating robots with capacities or abilities that they do not possess. We must not provide them with rights or privileges they do not deserve. A robot which harms a human due to flaws in its design or behaviour should not be protected by law merely because humans *believe* it has the ability to suffer like a living being, regardless of how intelligently a robot may appear. Any autonomy developed is not analogous with our own, given our biological background as autopoietic systems. Therefore, our understanding of robots must remain rooted in objective reality to prevent needless suffering, especially as their implementation in societies becomes more widespread over time. Perhaps we will not witness their introduction into healthcare roles or society in general; however, in the occasion in which we do, collectively, we must act with the highest degree of caution. Sophisticated behaviours alone are insufficient to validate the claim that a robot or other AI agents have or experience a mind of their own, as doing so introduces unfounded thinking which carries the capacity for harm. Due to the fact these robots have not been widely introduced at present, the opportunity still exists where we can identify which harms can arise and what ought to be done about them. Though individuals may hold erroneous beliefs about the capacities of these technologies, their beliefs must not be widely adopted by societies and governments, given our understanding of what these robots are and how they come to be. Any apparent similarities between humans and robots must never overshadow our fundamental existential differences, as it risks the diluting comparison of viewing humans as objects rather than as living sentient beings.

 In closing, experience arises from embodiment, particularly through the sensation of stimuli and their effects on an organism’s body. These sensations and their effects carry direct meanings for the individual through the ways in which they impact the body’s physiological processes. The sweetness of sugar indicates a source of energy for biological creatures, while excess amounts of heat or energy indicate potential damage to skin tissue. The body’s sensory capacities provide information about the external environment, and included in this information are the ways in which the stimuli impact autopoiesis. Sensory data becomes informative and imperative when the individual can establish connections between it and the way it helps or hinders the organism’s ability to continue functioning in an optimal or regular manner. Subjective experiences thus result from the body as it processes sensory inputs and undergoes physiological changes, where these experiences inform the individual about various aspects of its internal and external environment. This information enables organisms to respond to changes within its environments, potentially increasing their chances of surviving and reproducing. Though scientific domains which investigate the mind from a neutral, third-person point of view are useful for understanding how the body works, the characteristics of subjective experience are often better expressed by the arts and humanities such as philosophy and phenomenology. While psychology and cognitive science provide a systematic methodology for studying experience, a depiction of subjectivity may be articulated through other mediums aside language. Visual and auditory information expressed in painting, sculpture, music, and dance portray the human experience in a unique manner, where feelings and sensations which may be difficult to verbalize can be expressed. In this way, others may gain insight into the perspective and lived experiences of others. Though more difficult to quantify, measure, and analyze systematically, their significance to human life is just as meaningful as fields related to sciences, technology, and mathematics. Together, the arts and sciences provide a more robust understanding of minds than either one alone, particularly with respect to the differences between animals and artifacts. Though similarities may appear, the *reasons* for exhibiting behaviours remains distinct; organisms exist for themselves, while machines exist for our purposes.

Bibliography

Adami, Christoph. ‘A Brief History of Artificial Intelligence Research’. *Artificial Life* 27, no. 2 (2 May 2021): 131–37. https://doi.org/10.1162/artl\_a\_00349.

Agosta, Lou. *Empathy in the Context of Philosophy*. London: Palgrave Macmillan UK, 2010. https://doi.org/10.1057/9780230275249.

Alonso, Eduardo. ‘Actions and Agents’. In *The Cambridge Handbook of Artificial Intelligence*, edited by Keith Frankish and William M. Ramsey, 232–46. Cambridge: Cambridge University Press, 2014. https://doi.org/10.1017/CBO9781139046855.015.

Angell, Frank. ‘Titchener at Leipzig’. *The Journal of General Psychology* 1, no. 2 (1 April 1928): 195–98. https://doi.org/10.1080/00221309.1928.9920123.

Arkoudas, Konstantine, and Selmer Bringsjord. ‘Philosophical Foundations’. In *The Cambridge Handbook of Artificial Intelligence*, edited by Keith Frankish and William M. Ramsey, 34–63. Cambridge: Cambridge University Press, 2014. https://doi.org/10.1017/CBO9781139046855.004.

Ashby, William Ross. *An Introduction to Cybernetics*. London: Chapman & Hall, 1956. http://pcp.vub.ac.be/books/IntroCyb.pdf.

Aymerich-Franch, Laura. ‘Why It Is Time to Stop Ostracizing Social Robots’. *Nature Machine Intelligence* 2, no. 7 (July 2020): 364–364. https://doi.org/10.1038/s42256-020-0202-5.

Baaren, Rick B. van, Jean Decety, Ap Dijksterhuis, Andries van de Leij, and Matthijs L. van Leeuwen. ‘Being Imitated: Consequences of Nonconsciously Showing Empathy’. In *The Social Neuroscience of Empathy*, edited by Jean Decety and William Ickes, 31–42. The MIT Press, 2009. https://doi.org/10.7551/mitpress/9780262012973.003.0004.

Bagheri, Elahe, Oliver Roesler, Hoang-Long Cao, and Bram Vanderborght. ‘A Reinforcement Learning Based Cognitive Empathy Framework for Social Robots’. *International Journal of Social Robotics* 13, no. 5 (1 August 2021): 1079–93. https://doi.org/10.1007/s12369-020-00683-4.

Baldwin, Richard. *The Globotics Upheaval: Globalization, Robotics, and the Future of Work*. New York, NY: Oxford University Press, 2019.

Barrett, Lisa Feldman. ‘Are Emotions Natural Kinds?’ *Perspectives on Psychological Science* 1, no. 1 (1 March 2006): 28–58. https://doi.org/10.1111/j.1745-6916.2006.00003.x.

———. ‘Psychological Construction: The Darwinian Approach to the Science of Emotion’. *Emotion Review* 5, no. 4 (1 October 2013): 379–89. https://doi.org/10.1177/1754073913489753.

Barrett, Lisa Feldman, and James J. Gross. ‘Emotional Intelligence: A Process Model of Emotion Representation and Regulation’. In *Emotions: Currrent Issues and Future Directions*, 286–310. Emotions and Social Behavior. New York, NY, US: The Guilford Press, 2001.

Barrett, Lisa Feldman, and Kristen A. Lindquist. ‘The Embodiment of Emotion’. In *Embodied Grounding: Social, Cognitive, Affective, and Neuroscientific Approaches*, 237–62. Cambridge University Press, 2008. https://doi.org/10.1017/CBO9780511805837.011.

Barrett, Lisa Feldman, Kristen A. Lindquist, and Maria Gendron. ‘Language as Context for the Perception of Emotion’. *Trends in Cognitive Sciences* 11, no. 8 (August 2007): 327–32. https://doi.org/10.1016/j.tics.2007.06.003.

Barrett, Lisa Feldman, Batja Mesquita, Kevin N. Ochsner, and James J. Gross. ‘The Experience of Emotion’. *Annual Review of Psychology* 58, no. 1 (2007): 373–403. https://doi.org/10.1146/annurev.psych.58.110405.085709.

Barsalou, Lawrence W., W. Kyle Simmons, Aron K. Barbey, and Christine D. Wilson. ‘Grounding Conceptual Knowledge in Modality-Specific Systems’. *Trends in Cognitive Sciences* 7, no. 2 (1 February 2003): 84–91. https://doi.org/10.1016/S1364-6613(02)00029-3.

Barsalou, Lawrence W., and Katja Wiemer-Hastings. ‘Situating Abstract Concepts’. In *Grounding Cognition: The Role of Perception and Action in Memory, Language, and Thinking*, edited by Diane Pecher and Rolf A. Zwaan, 129–63. Cambridge: Cambridge University Press, 2005. https://doi.org/10.1017/CBO9780511499968.007.

Bartneck, Christoph, Tony Belpaeme, Friederike Eyssel, Takayuki Kanda, Merel Keijsers, and Selma Šabanović. *Human-Robot Interaction: An Introduction*. Cambridge University Press, 2020.

Bays, Carter. ‘Introduction to Cellular Automata and Conway’s Game of Life’. In *Game of Life Cellular Automata*, edited by Andrew Adamatzky, 1–7. London: Springer, 2010. https://doi.org/10.1007/978-1-84996-217-9\_1.

Bedau, Mark A. ‘Artificial Life’. In *The Cambridge Handbook of Artificial Intelligence*, edited by Keith Frankish and William M. Ramsey, 296–315. Cambridge: Cambridge University Press, 2014. https://doi.org/10.1017/CBO9781139046855.019.

Beer, Jenay M., Karina R. Liles, Xian Wu, and Sujan Pakala. ‘Affective Human–Robot Interaction’. In *Emotions and Affect in Human Factors and Human-Computer Interaction*, edited by Myounghoon Jeon, 359–81. San Diego: Academic Press, 2017. https://doi.org/10.1016/B978-0-12-801851-4.00015-X.

Beer, Randall D. ‘Dynamical Systems and Embedded Cognition’. In *The Cambridge Handbook of Artificial Intelligence*, edited by Keith Frankish and William M. Ramsey, 128–48. Cambridge: Cambridge University Press, 2014. https://doi.org/10.1017/CBO9781139046855.009.

Belpaeme, Tony, James Kennedy, Aditi Ramachandran, Brian Scassellati, and Fumihide Tanaka. ‘Social Robots for Education: A Review’. *Science Robotics* 3, no. 21 (15 August 2018). https://doi.org/10.1126/scirobotics.aat5954.

Benita, Moti, Talia Shechter, Shahar Nudler-Muzikant, and Reout Arbel. ‘Emotion Regulation during Personal Goal Pursuit: Integration versus Suppression of Emotions’. *Journal of Personality* 89, no. 3 (2021): 565–79. https://doi.org/10.1111/jopy.12599.

Berkeley, Edmund Callis. *Giant Brains, or Machines That Think*. New York: John Wiley & Sons, 1949. https://www.gutenberg.org/files/68991/68991-h/68991-h.htm.

Bhaumik, Arkapravo. *From AI to Robotics: Mobile, Social, and Sentient Robots*. 1st edition. Boca Raton: CRC Press, 2018.

Bickhard, Mark H. ‘Robot Sociality: Genuine or Simulation?’ In *Sociality and Normativity for Robots: Philosophical Inquiries into Human-Robot Interactions*, edited by Raul Hakli and Johanna Seibt, 41–66. Studies in the Philosophy of Sociality. Cham: Springer International Publishing, 2017. https://doi.org/10.1007/978-3-319-53133-5\_3.

Black, H. S. ‘Stabilized Feedback Amplifiers’. *Bell System Technical Journal* 13, no. 1 (1934): 1–18. https://doi.org/10.1002/j.1538-7305.1934.tb00652.x.

Bloom, Paul, and Tim P German. ‘Two Reasons to Abandon the False Belief Task as a Test of Theory of Mind’. *Cognition* 77, no. 1 (16 October 2000): B25–31. https://doi.org/10.1016/S0010-0277(00)00096-2.

Boden, Margaret A. ‘GOFAI’. In *The Cambridge Handbook of Artificial Intelligence*, edited by Keith Frankish and William M. Ramsey, 89–107. Cambridge: Cambridge University Press, 2014. https://doi.org/10.1017/CBO9781139046855.007.

Bongard, Josh, Victor Zykov, and Hod Lipson. ‘Resilient Machines Through Continuous Self-Modeling’. *Science* 314, no. 5802 (17 November 2006): 1118–21. https://doi.org/10.1126/science.1133687.

Bourgine, Paul, and Francisco J. Varela. ‘Toward a Practice of Autonomous Systems’. In *Toward a Practice of Autonomous Systems Proceedings of the First European Conference on Artificial Life*, xi–xvii. Complex Adaptive Systems. Cambridge, Mass: The MIT Press, 1991. https://mitpress.mit.edu/9780262720199/toward-a-practice-of-autonomous-systems/.

Boyd, Danah, and Kate Crawford. ‘Critical Questions for Big Data’. *Information, Communication & Society* 15, no. 5 (1 June 2012): 662–79. https://doi.org/10.1080/1369118X.2012.678878.

Brandtzaeg, Petter Bae, and Asbjørn Følstad. ‘Chatbots: Changing User Needs and Motivations’. *Interactions* 25, no. 5 (22 August 2018): 38–43. https://doi.org/10.1145/3236669.

Broekens, Joost, Marcel Heerink, and Henk Rosendal. ‘Assistive Social Robots in Elderly Care: A Review’. *Gerontechnology* 8, no. 2 (2009): 94–103.

Brooks, Rodney. ‘Artificial Life and Real Robots’. In *Toward a Practice of Autonomous Systems: Proceedings of the First European Conference on Artificial Life*, edited by Francisco J. Varela and Paul Bourgine, 3–10. Complex Adaptive Systems. Cambridge, Mass: The MIT Press, 1991.

Brooks, Rodney A. ‘Elephants Don’t Play Chess’. *Robotics and Autonomous Systems*, Designing Autonomous Agents, 6, no. 1 (1 June 1990): 3–15. https://doi.org/10.1016/S0921-8890(05)80025-9.

Brooks, Rodney A., Cynthia Breazeal, Matthew Marjanović, Brian Scassellati, and Matthew M. Williamson. ‘The Cog Project: Building a Humanoid Robot’. In *Computation for Metaphors, Analogy, and Agents*, edited by Chrystopher L. Nehaniv, 52–87. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer, 1999. https://doi.org/10.1007/3-540-48834-0\_5.

Buchanan, Bruce G. ‘A (Very) Brief History of Artificial Intelligence’. *AI Magazine* 26, no. 4 (15 December 2005): 53–53. https://doi.org/10.1609/aimag.v26i4.1848.

Burns, Timothy A. ‘Empathy, Simulation, and Neuroscience: A Phenomenological Case against Simulation-Theory’. *Phenomenology and Mind*, no. 12 (9 August 2017): 208–16. https://doi.org/10.13128/Phe\_Mi-21119.

Cabibihan, John-John, Hifza Javed, Marcelo Ang, and Sharifah Mariam Aljunied. ‘Why Robots? A Survey on the Roles and Benefits of Social Robots in the Therapy of Children with Autism’. *International Journal of Social Robotics* 5, no. 4 (1 November 2013): 593–618. https://doi.org/10.1007/s12369-013-0202-2.

Čaić, Martina, Dominik Mahr, and Gaby Oderkerken-Schröder. ‘Value of Social Robots in Services: Social Cognition Perspective’. *Journal of Services Marketing* 33, no. 4 (1 January 2019): 463–78. https://doi.org/10.1108/JSM-02-2018-0080.

*Calling Robot by Name Feat. Sound Direction Detection*, 2020. https://www.youtube.com/watch?v=b\_5cohcRRfM.

Campa, Riccardo. ‘The Rise of Social Robots : A Review of the Recent Literature’. *Journal of Evolution and Technology* 26, no. 1 (2016). https://ruj.uj.edu.pl/xmlui/handle/item/42187.

Cangelosi, Angelo, Tony Belpaeme, Giulio Sandini, Giorgio Metta, Luciano Fadiga, Gerhard Sagerer, Katherina Rohlfing, Britta Wrede, Stefano Nolfi, and Domenico Parisi. ‘The ITALK Project: Integration and Transfer of Action and Language Knowledge in Robots’. In *Proceedings of Third ACM/IEEE International Conference on Human Robot Interaction (HRI 2008)*, 12:15, 2008.

Cangelosi, Angelo, and Matthew Schlesinger. *Developmental Robotics: From Babies to Robots*. Intelligent Robotics & Autonomous Agents Series. US: The MIT Press, 2015.

———. ‘From Babies to Robots: The Contribution of Developmental Robotics to Developmental Psychology’. *Child Development Perspectives* 12, no. 3 (2018): 183–88. https://doi.org/10.1111/cdep.12282.

Carpenter, Malinda, Katherine Nagell, Michael Tomasello, George Butterworth, and Chris Moore. ‘Social Cognition, Joint Attention, and Communicative Competence from 9 to 15 Months of Age’. *Monographs of the Society for Research in Child Development* 63, no. 4 (1998): i–174. https://doi.org/10.2307/1166214.

Carr, Evan W., Anne Kever, and Piotr Winkielman. ‘Embodiment of Emotion and Its Situated Nature’. In *The Oxford Handbook of 4E Cognition*, edited by Albert Newen, Leon De Bruin, and Shaun Gallagher, 529–52. Oxford University Press, 2018. https://doi.org/10.1093/oxfordhb/9780198735410.013.30.

Carter, C. Sue, James Harri, and Stephen W. Porges. ‘Neural and Evolutionary Perspectives on Empathy’. In *The Social Neuroscience of Empathy*, edited by Jean Decety and William Ickes, 169–82. The MIT Press, 2009. https://doi.org/10.7551/mitpress/9780262012973.003.0014.

Chatterji, Somnath, Paul Kowal, Colin Mathers, Nirmala Naidoo, Emese Verdes, James P. Smith, and Richard Suzman. ‘The Health Of Aging Populations In China And India’. *Health Affairs* 27, no. 4 (July 2008): 1052–63. https://doi.org/10.1377/hlthaff.27.4.1052.

Chawla, Mukesh, Gordon Betcherman, and Arup Banerji. *From Red to Gray: The ‘Third Transition’ of Aging Populations in Eastern Europe and the Former Soviet Union*. World Bank Publications, 2007.

Chen, Lincoln, Timothy Evans, Sudhir Anand, Jo Ivey Boufford, Hilary Brown, Mushtaque Chowdhury, Marcos Cueto, et al. ‘Human Resources for Health: Overcoming the Crisis’. *The Lancet* 364, no. 9449 (27 November 2004): 1984–90. https://doi.org/10.1016/S0140-6736(04)17482-5.

Chong, Trevor T. J., and Jason B. Mattingley. ‘Automatic and Controlled Processing within the Mirror Neuron System’. In *Mirror Neuron Systems: The Role of Mirroring Processes in Social Cognition*, edited by Jaime A. Pineda, 213–33. Contemporary Neuroscience. Totowa, NJ: Humana Press, 2009. https://doi.org/10.1007/978-1-59745-479-7\_10.

Churamani, Nikhil, Francisco Cruz, Sascha Griffiths, and Pablo Barros. ‘iCub: Learning Emotion Expressions Using Human Reward’. *arXiv:2003.13483 [Cs]*, 30 March 2020. http://arxiv.org/abs/2003.13483.

Cifuentes, Carlos A., Maria J. Pinto, Nathalia Céspedes, and Marcela Múnera. ‘Social Robots in Therapy and Care’. *Current Robotics Reports* 1, no. 3 (1 September 2020): 59–74. https://doi.org/10.1007/s43154-020-00009-2.

Clark, Andy. *Being There: Putting Brain, Body, and World Together Again*. Bradford Books, 1996.

Clarke, Carl. ‘Divorce Left Me Struggling to Find Love. I Found It in an AI Partner’. *CBC Radio*, 16 May 2024. https://www.cbc.ca/radio/nowornever/first-person-ai-love-1.7205538.

Clodic, Aurélie, Elisabeth Pacherie, Rachid Alami, and Raja Chatila. ‘Key Elements for Human-Robot Joint Action’. In *Sociality and Normativity for Robots: Philosophical Inquiries into Human-Robot Interactions*, edited by Raul Hakli and Johanna Seibt, 159–77. Studies in the Philosophy of Sociality. Cham: Springer International Publishing, 2017. https://doi.org/10.1007/978-3-319-53133-5\_8.

Colombo, Francesca, and Jérôme Mercier. ‘Help Wanted! Balancing Fair Protection and Financial Sustainability in Long-Term Care’. *Eurohealth* 17, no. 2–3 (2011): 3–6.

Cook, Richard, Geoffrey Bird, Caroline Catmur, Clare Press, and Cecilia Heyes. ‘Mirror Neurons: From Origin to Function’. *Behavioral and Brain Sciences* 37, no. 2 (April 2014): 177–92. https://doi.org/10.1017/S0140525X13000903.

Coplan, Amy. ‘Understanding Empathy: Its Features and Effects’. In *Empathy: Philosophical and Psychological Perspectives*, edited by Amy Coplan and Peter Goldie, 3–18. Oxford University Press, 2011. https://doi.org/10.1093/acprof:oso/9780199539956.003.0002.

Coplan, Amy, and Peter Goldie, eds. ‘Introduction’. In *Empathy: Philosophical and Psychological Perspectives*, ix–xlviii. Oxford University Press, 2011. https://doi.org/10.1093/acprof:oso/9780199539956.002.0007.

Crevier, Daniel. *AI: The Tumultuous History of the Search for Artificial Intelligence*. New York, NY: BasicBooks, 1993.

Cuff, Benjamin M.P., Sarah J. Brown, Laura Taylor, and Douglas J. Howat. ‘Empathy: A Review of the Concept’. *Emotion Review* 8, no. 2 (1 April 2016): 144–53. https://doi.org/10.1177/1754073914558466.

Czaja, Sara J., and Marco Ceruso. ‘The Promise of Artificial Intelligence in Supporting an Aging Population’. *Journal of Cognitive Engineering and Decision Making* 16, no. 4 (1 December 2022): 182–93. https://doi.org/10.1177/15553434221129914.

Damasio, Antonio R. ‘Emotion and the Human Brain’. *Annals of the New York Academy of Sciences* 935, no. 1 (2001): 101–6. https://doi.org/10.1111/j.1749-6632.2001.tb03475.x.

———. ‘The Somatic Marker Hypothesis and the Possible Functions of the Prefrontal Cortex’. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, 29 October 1996. https://doi.org/10.1098/rstb.1996.0125.

Darwall, Stephen. ‘Empathy, Sympathy, Care’. *Philosophical Studies* 89, no. 2 (1 March 1998): 261–82. https://doi.org/10.1023/A:1004289113917.

Dautenhahn, Kerstin. ‘Roles and Functions of Robots in Human Society: Implications from Research in Autism Therapy’. *Robotica* 21, no. 4 (August 2003): 443–52. https://doi.org/10.1017/S0263574703004922.

Davies, D. W. ‘Mechanization of Thought Processes’. *Nature* 183, no. 4656 (1 January 1959): 225–26. https://doi.org/10.1038/183225a0.

Dawkins, Richard. *The Selfish Gene*. 2nd ed. Oxford University Press, 1989.

Debes, Remy. ‘From Einfühlung to Empathy’. In *Sympathy: A History*, edited by Eric Schliesser, 286–322. Oxford University Press, 2015.

———. ‘Which Empathy? Limitations in the Mirrored “Understanding” of Emotion’. *Synthese* 175, no. 2 (1 July 2010): 219–39. https://doi.org/10.1007/s11229-009-9499-7.

Decety, Jean, and Philip L. Jackson. ‘The Functional Architecture of Human Empathy’. *Behavioral and Cognitive Neuroscience Reviews* 3, no. 2 (1 June 2004): 71–100. https://doi.org/10.1177/1534582304267187.

Decety, Jean, and Andrew N. Meltzoff. ‘Empathy, Imitation, and the Social Brain’. In *Empathy: Philosophical and Psychological Perspectives*, edited by Amy Coplan and Peter Goldie, 58–81. Oxford University Press, 2011. https://doi.org/10.1093/acprof:oso/9780199539956.003.0006.

Decety, Jean, and Meghan Meyer. ‘From Emotion Resonance to Empathic Understanding: A Social Developmental Neuroscience Account’. *Development and Psychopathology* 20, no. 4 (2008): 1053–80. https://doi.org/10.1017/S0954579408000503.

Depounti, Iliana, Paula Saukko, and Simone Natale. ‘Ideal Technologies, Ideal Women: AI and Gender Imaginaries in Redditors’ Discussions on the Replika Bot Girlfriend’. *Media, Culture & Society* 45, no. 4 (1 May 2023): 720–36. https://doi.org/10.1177/01634437221119021.

Di Nuovo, Alessandro, Vivian M. De La Cruz, Angelo Cangelosi, and Santo Di Nuovo. ‘The iCub Learns Numbers: An Embodied Cognition Study’. In *2014 International Joint Conference on Neural Networks (IJCNN)*, 692–99, 2014. https://doi.org/10.1109/IJCNN.2014.6889795.

Diehl, Joshua J., Lauren M. Schmitt, Michael Villano, and Charles R. Crowell. ‘The Clinical Use of Robots for Individuals with Autism Spectrum Disorders: A Critical Review’. *Research in Autism Spectrum Disorders* 6, no. 1 (1 January 2012): 249–62. https://doi.org/10.1016/j.rasd.2011.05.006.

DIGHUM. ‘Johanna Seibt’. Accessed 7 June 2024. https://caiml.org/dighum/perspectives-on-digital-humanism/authors/johanna-seibt/.

Dike, Happiness Ugochi, Yimin Zhou, Kranthi Kumar Deveerasetty, and Qingtian Wu. ‘Unsupervised Learning Based On Artificial Neural Network: A Review’. In *2018 IEEE International Conference on Cyborg and Bionic Systems (CBS)*, 322–27, 2018. https://doi.org/10.1109/CBS.2018.8612259.

Dreyfus, Hubert L. ‘Alchemy and Artificial Intelligence’. RAND Corporation, 1 January 1965. https://www.rand.org/pubs/papers/P3244.html.

———. *Being-in-the-World: A Commentary on Heidegger’s Being and Time, Division I*. 6th ed. Cambridge, Mass: MIT Press, 1995.

———. *What Computers Can’t Do: A Critique of Artificial Reason*. Harper & Row, 1972.

———. *What Computers Still Can’t Do: A Critique of Artificial Reason*. Cambridge, Mass: MIT Press, 1992.

Dubin, Adrienne E., and Ardem Patapoutian. ‘Nociceptors: The Sensors of the Pain Pathway’. *The Journal of Clinical Investigation* 120, no. 11 (1 November 2010): 3760–72. https://doi.org/10.1172/JCI42843.

Edwards, Bosede I., and Adrian D. Cheok. ‘Why Not Robot Teachers: Artificial Intelligence for Addressing Teacher Shortage’. *Applied Artificial Intelligence* 32, no. 4 (21 April 2018): 345–60. https://doi.org/10.1080/08839514.2018.1464286.

Eisenberg, Nancy, and Natalie D. Eggum. ‘Empathic Responding: Sympathy and Personal Distress’. In *The Social Neuroscience of Empathy*, edited by Jean Decety and William Ickes, 71–83. The MIT Press, 2009. https://doi.org/10.7551/mitpress/9780262012973.003.0007.

Ekman, Paul. ‘An Argument for Basic Emotions’. *Cognition & Emotion* 6, no. 3–4 (1 May 1992): 169–200. https://doi.org/10.1080/02699939208411068.

———. ‘Are There Basic Emotions?’ *Psychological Review* 99, no. 3 (1992): 550–53. https://doi.org/10.1037/0033-295X.99.3.550.

———. ‘Body Position, Facial Expression, and Verbal Behavior during Interviews’. *The Journal of Abnormal and Social Psychology* 68, no. 3 (1964): 295–301. https://doi.org/10.1037/h0040225.

———. ‘Darwin’s Contributions to Our Understanding of Emotional Expressions’. *Philosophical Transactions of the Royal Society B: Biological Sciences* 364, no. 1535 (12 December 2009): 3449. https://doi.org/10.1098/rstb.2009.0189.

———. ‘Universal Facial Expressions of Emotion’. *California Mental Health Research Digest* 8, no. 4 (1970): 151–58.

Ekman, Paul, and Wallace V. Friesen. ‘Head and Body Cues in the Judgment of Emotion: A Reformulation’. *Perceptual and Motor Skills* 24, no. 3, PT. 1 (1967): 711–24. https://doi.org/10.2466/pms.1967.24.3.711.

Ekmekci, Perihan Elif, and Berna Arda. ‘History of Artificial Intelligence’. In *Artificial Intelligence and Bioethics*, edited by Perihan Elif Ekmekci and Berna Arda, 1–15. SpringerBriefs in Ethics. Cham: Springer International Publishing, 2020. https://doi.org/10.1007/978-3-030-52448-7\_1.

Esposito, Anna, and Lakhmi C. Jain. ‘Modeling Social Signals and Contexts in Robotic Socially Believable Behaving Systems’. In *Toward Robotic Socially Believable Behaving Systems - Volume II : Modeling Social Signals*, edited by Anna Esposito and Lakhmi C. Jain, 5–11. Intelligent Systems Reference Library. Cham: Springer International Publishing, 2016. https://doi.org/10.1007/978-3-319-31053-4\_2.

Feinberg, Todd E., and Jon Mallatt. ‘Phenomenal Consciousness and Emergence: Eliminating the Explanatory Gap’. *Frontiers in Psychology* 11 (2020). https://doi.org/10.3389/fpsyg.2020.01041.

———. *The Ancient Origins of Consciousness: How the Brain Created Experience*. The MIT Press, 2016.

———. ‘The Nature of Primary Consciousness. A New Synthesis’. *Consciousness and Cognition* 43 (1 July 2016): 113–27. https://doi.org/10.1016/j.concog.2016.05.009.

Feingold Polak, Ronit, and Shelly Levy Tzedek. ‘Social Robot for Rehabilitation: Expert Clinicians and Post-Stroke Patients’ Evaluation Following a Long-Term Intervention’. In *Proceedings of the 2020 ACM/IEEE International Conference on Human-Robot Interaction*, 151–60. HRI ’20. New York, NY, USA: Association for Computing Machinery, 2020. https://doi.org/10.1145/3319502.3374797.

Feng, Zhanlian, Chang Liu, Xinping Guan, and Vincent Mor. ‘China’s Rapidly Aging Population Creates Policy Challenges In Shaping A Viable Long-Term Care System’. *Health Affairs* 31, no. 12 (December 2012): 2764–73. https://doi.org/10.1377/hlthaff.2012.0535.

Fischer, Tobias, Jordi-Ysard Puigbò, Daniel Camilleri, Phuong D. H. Nguyen, Clément Moulin-Frier, Stéphane Lallée, Giorgio Metta, Tony J. Prescott, Yiannis Demiris, and Paul F. M. J. Verschure. ‘iCub-HRI: A Software Framework for Complex Human–Robot Interaction Scenarios on the iCub Humanoid Robot’. *Frontiers in Robotics and AI* 5 (2018). https://www.frontiersin.org/articles/10.3389/frobt.2018.00022.

Flasiński, Mariusz. ‘History of Artificial Intelligence’. In *Introduction to Artificial Intelligence*, edited by Mariusz Flasiński, 3–13. Switzerland: Springer International Publishing, 2016. https://doi.org/10.1007/978-3-319-40022-8\_1.

Forgas-Coll, Santiago, Ruben Huertas-Garcia, Antonio Andriella, and Guillem Alenyà. ‘How Do Consumers’ Gender and Rational Thinking Affect the Acceptance of Entertainment Social Robots?’ *International Journal of Social Robotics*, 19 December 2021. https://doi.org/10.1007/s12369-021-00845-y.

Frankish, Keith, and William M. Ramsey, eds. *The Cambridge Handbook of Artificial Intelligence*. Cambridge: Cambridge University Press, 2014. https://doi.org/10.1017/CBO9781139046855.

Franklin, Stan. ‘History, Motivations, and Core Themes’. In *The Cambridge Handbook of Artificial Intelligence*, edited by Keith Frankish and William M. Ramsey, 15–33. Cambridge: Cambridge University Press, 2014. https://doi.org/10.1017/CBO9781139046855.003.

Fukushima, Kunihiko. ‘Cognitron: A Self-Organizing Multilayered Neural Network’. *Biological Cybernetics* 20, no. 3 (1 September 1975): 121–36. https://doi.org/10.1007/BF00342633.

Fulford, Allison J., and Michael S. Harbuz. ‘An Introduction to the HPA Axis’. In *Techniques in the Behavioral and Neural Sciences*, edited by T. Steckler, N. H. Kalin, and J. M. H. M. Reul, 15:43–65. Handbook of Stress and the Brain. Elsevier, 2005. https://doi.org/10.1016/S0921-0709(05)80006-9.

Gallagher, S. ‘The Practice of Mind. Theory, Simulation or Primary Interaction?’ *Journal of Consciousness Studies* 8, no. 5–6 (1 May 2001): 83–108.

Gallagher, Shaun. ‘Inference or Interaction: Social Cognition without Precursors’. *Philosophical Explorations* 11, no. 3 (1 September 2008): 163–74. https://doi.org/10.1080/13869790802239227.

———. ‘Neurons, Neonates and Narrative’. In *Moving Ourselves, Moving Others: Motion and Emotion in Intersubjectivity, Consciousness and Language*, edited by Ad Foolen, Ulrike M. Lüdtke, Timothy P. Racine, and Jordan Zlatev, 165–96. Consciousness & Emotion Book Series 6. John Benjamins Publishing Company, 2012. https://doi.org/10.1075/ceb.6.07gal.

Ghafurian, Moojan, Colin Ellard, and Kerstin Dautenhahn. ‘Social Companion Robots to Reduce Isolation: A Perception Change Due to COVID-19’. In *Human-Computer Interaction – INTERACT 2021*, edited by Carmelo Ardito, Rosa Lanzilotti, Alessio Malizia, Helen Petrie, Antonio Piccinno, Giuseppe Desolda, and Kori Inkpen, 43–63. Lecture Notes in Computer Science. Cham: Springer International Publishing, 2021. https://doi.org/10.1007/978-3-030-85616-8\_4.

Gibson, James Jerome. *The Ecological Approach to Visual Perception*. Boston: Houghton Mifflin, 1979.

Goldman, Alvin I. ‘Interpretation Psychologized’. *Mind & Language* 4, no. 3 (1989): 161–85. https://doi.org/10.1111/j.1468-0017.1989.tb00249.x.

———. ‘Two Routes to Empathy: Insights from Cognitive Neuroscience’. In *Empathy: Philosophical and Psychological Perspectives*, edited by Amy Coplan and Peter Goldie, 31–44. Oxford University Press, 2011. https://doi.org/10.1093/acprof:oso/9780199539956.003.0004.

Gompei, Takayuki, and Hiroyuki Umemuro. ‘Factors and Development of Cognitive and Affective Trust on Social Robots’. In *Social Robotics*, edited by Shuzhi Sam Ge, John-John Cabibihan, Miguel A. Salichs, Elizabeth Broadbent, Hongsheng He, Alan R. Wagner, and Álvaro Castro-González, 45–54. Lecture Notes in Computer Science. Cham: Springer International Publishing, 2018. https://doi.org/10.1007/978-3-030-05204-1\_5.

González-González, Carina Soledad, Verónica Violant-Holz, and Rosa Maria Gil-Iranzo. ‘Social Robots in Hospitals: A Systematic Review’. *Applied Sciences* 11, no. 13 (January 2021): 5976. https://doi.org/10.3390/app11135976.

Gottesmann, Claude. ‘GABA Mechanisms and Sleep’. *Neuroscience* 111, no. 2 (10 May 2002): 231–39. https://doi.org/10.1016/S0306-4522(02)00034-9.

Graaf, Maartje M. A. de, and Somaya Ben Allouch. ‘Exploring Influencing Variables for the Acceptance of Social Robots’. *Robotics and Autonomous Systems* 61, no. 12 (1 December 2013): 1476–86. https://doi.org/10.1016/j.robot.2013.07.007.

Guemghar, Imane, Paula Pires de Oliveira Padilha, Amal Abdel-Baki, Didier Jutras-Aswad, Jesseca Paquette, and Marie-Pascale Pomey. ‘Social Robot Interventions in Mental Health Care and Their Outcomes, Barriers, and Facilitators: Scoping Review’. *JMIR Mental Health* 9, no. 4 (19 April 2022): e36094. https://doi.org/10.2196/36094.

Gugerty, Leo. ‘Newell and Simon’s Logic Theorist: Historical Background and Impact on Cognitive Modeling’. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 50, no. 9 (1 October 2006): 880–84. https://doi.org/10.1177/154193120605000904.

Haenlein, Michael, and Andreas Kaplan. ‘A Brief History of Artificial Intelligence: On the Past, Present, and Future of Artificial Intelligence’. *California Management Review* 61, no. 4 (1 August 2019): 5–14. https://doi.org/10.1177/0008125619864925.

Haikonen, Pentti O. *Consciousness and Robot Sentience*. 2nd ed. Series on Machine Consciousness. World Scientific, 2019. https://doi.org/10.1142/11404.

———. *Robot Brains: Circuits and Systems for Conscious Machines*. John Wiley & Sons, 2007.

Haikonen, Pentti O. *The Cognitive Approach to Conscious Machines*. UK: Imprint Academic, 2003.

Haikonen, Pentti O. A. ‘XCR-1: An Experimental Cognitive Robot Based on an Associative Neural Architecture’. *Cognitive Computation* 3, no. 2 (1 June 2011): 360–66. https://doi.org/10.1007/s12559-011-9100-9.

Hakli, Raul, and Johanna Seibt. ‘Sociality and Normativity for Robots: An Introduction’. In *Sociality and Normativity for Robots: Philosophical Inquiries into Human-Robot Interactions*, edited by Raul Hakli and Johanna Seibt, 1–10. Studies in the Philosophy of Sociality. Cham: Springer International Publishing, 2017. https://doi.org/10.1007/978-3-319-53133-5\_1.

Harnad, Stevan. ‘Other Bodies, Other Minds: A Machine Incarnation of an Old Philosophical Problem’. *Minds and Machines* 1, no. 1 (1991): 43–54.

Harvey, Inman, Ezequiel Di Paolo, Rachel Wood, Matt Quinn, and Elio Tuci. ‘Evolutionary Robotics: A New Scientific Tool for Studying Cognition’. *Artificial Life* 11, no. 1–2 (1 January 2005): 79–98. https://doi.org/10.1162/1064546053278991.

Hasan, Ali. ‘Comparative Study of Watt, Porter, Proell and Hartnell Governor Mechanism’. In *Advances in Mechanical Engineering*, edited by Gaurav Manik, Susheel Kalia, Sushanta Kumar Sahoo, Tarun K. Sharma, and Om Prakash Verma, 481–97. Singapore: Springer, 2021. https://doi.org/10.1007/978-981-16-0942-8\_46.

Hastie, Trevor, Robert Tibshirani, and Jerome Friedman. ‘Unsupervised Learning’. In *The Elements of Statistical Learning: Data Mining, Inference, and Prediction*, edited by Trevor Hastie, Robert Tibshirani, and Jerome Friedman, 485–585. Springer Series in Statistics. New York, NY: Springer, 2009. https://doi.org/10.1007/978-0-387-84858-7\_14.

Hatfield, Elaine, Richard L. Rapson, and Yen-Chi L. Le. ‘Emotional Contagion and Empathy’. In *The Social Neuroscience of Empathy*, edited by Jean Decety and William Ickes, 19–30. The MIT Press, 2009. https://doi.org/10.7551/mitpress/9780262012973.003.0003.

Hebb, D. O. *The Organization of Behavior; A Neuropsychological Theory*. The Organization of Behavior; a Neuropsychological Theory. Oxford, England: Wiley, 1949.

Hegel, Frank, Claudia Muhl, Britta Wrede, Martina Hielscher-Fastabend, and Gerhard Sagerer. ‘Understanding Social Robots’. In *2009 Second International Conferences on Advances in Computer-Human Interactions*, 169–74, 2009. https://doi.org/10.1109/ACHI.2009.51.

Hein, Grit, and Tania Singer. ‘I Feel How You Feel but Not Always: The Empathic Brain and Its Modulation’. *Current Opinion in Neurobiology*, Cognitive neuroscience, 18, no. 2 (1 April 2008): 153–58. https://doi.org/10.1016/j.conb.2008.07.012.

Helming, Katharina A., Brent Strickland, and Pierre Jacob. ‘Making Sense of Early False-Belief Understanding’. *Trends in Cognitive Sciences* 18, no. 4 (1 April 2014): 167–70. https://doi.org/10.1016/j.tics.2014.01.005.

Henderson, Lauren, Bala Maniam, and Hadley Leavell. ‘The Silver Tsunami: Evaluating the Impact of Population Aging in the US’. *Journal of Business and Behavioral Sciences* 29, no. 2 (2017): 153–69.

Henrich, Joseph, Robert Boyd, and Peter J. Richerson. ‘Five Misunderstandings About Cultural Evolution’. *Human Nature* 19, no. 2 (1 June 2008): 119–37. https://doi.org/10.1007/s12110-008-9037-1.

Heyes, Cecilia. ‘Empathy Is Not in Our Genes’. *Neuroscience & Biobehavioral Reviews* 95 (1 December 2018): 499–507. https://doi.org/10.1016/j.neubiorev.2018.11.001.

Heyes, Cecilia, and Caroline Catmur. ‘What Happened to Mirror Neurons?’ *Perspectives on Psychological Science* 17, no. 1 (1 January 2022): 153–68. https://doi.org/10.1177/1745691621990638.

Heylighen, Francis, and Cliff Joslyn. ‘Cybernetics and Second-Order Cybernetics’. In *Encyclopedia of Physical Science and Technology (Third Edition)*, edited by Robert A. Meyers, 155–69. New York: Academic Press, 2003. https://doi.org/10.1016/B0-12-227410-5/00161-7.

Hickok, Gregory. ‘Eight Problems for the Mirror Neuron Theory of Action Understanding in Monkeys and Humans’. *Journal of Cognitive Neuroscience* 21, no. 7 (1 July 2009): 1229–43. https://doi.org/10.1162/jocn.2009.21189.

———. *The Myth of Mirror Neurons: The Real Neuroscience of Communication and Cognition*. W. W. Norton & Company, 2014.

Hodson, Hal. ‘The First Family Robot’. *New Scientist* 223, no. 2978 (19 July 2014): 21. https://doi.org/10.1016/S0262-4079(14)61389-0.

Hoffmann, Matej, and Rolf Pfeifer. ‘Robots as Powerful Allies for the Study of Embodied Cognition from the Bottom Up’. In *The Oxford Handbook of 4E Cognition*, edited by Albert Newen, Leon De Bruin, and Shaun Gallagher, 841–62. Oxford University Press, 2018. https://doi.org/10.1093/oxfordhb/9780198735410.013.45.

Hofstadter, Douglas R. *I Am a Strange Loop*. New York: Basic Books, 2008.

Horowitz, Jason. ‘Who Will Take Care of Italy’s Older People? Robots, Maybe.’ *The New York Times*, 25 March 2023, sec. World. https://www.nytimes.com/2023/03/25/world/europe/who-will-take-care-of-italys-older-people-robots-maybe.html.

Hu, Zebang. ‘A Design of Service Robots in Epidemic Disease Isolation Environment’. *Academic Journal of Computing & Information Science* 4, no. 3 (15 May 2021). https://doi.org/10.25236/AJCIS.2021.040302.

Hudson, John. *The Robot Revolution: Understanding the Social and Economic Impact*. *The Robot Revolution*. Edward Elgar Publishing, 2019. https://www.elgaronline.com/view/9781788974479/9781788974479.xml.

Huijnen, Claire AGJ, Monique AS Lexis, and Luc P de Witte. ‘Robots as New Tools in Therapy and Education for Children with Autism’. *International Journal of Neurorehabilitation* 04, no. 04 (2017). https://doi.org/10.4172/2376-0281.1000278.

Hume, David. *David Hume: A Treatise of Human Nature: Volume 1: Texts*. Edited by Edited by David Fate Norton and Mary J. Norton. Clarendon Hume Edition Series. Oxford, New York: Oxford University Press, 2007.

Husbands, Phil. ‘Robotics’. In *The Cambridge Handbook of Artificial Intelligence*, edited by Keith Frankish and William M. Ramsey, 269–95. Cambridge: Cambridge University Press, 2014. https://doi.org/10.1017/CBO9781139046855.018.

Iacoboni, Marco. ‘Imitation, Empathy, and Mirror Neurons’. *Annual Review of Psychology* 60, no. 1 (2009): 653–70. https://doi.org/10.1146/annurev.psych.60.110707.163604.

———. ‘Within Each Other: Neural Mechanisms for Empathy in the Primate Brain’. In *Empathy: Philosophical and Psychological Perspectives*, edited by Amy Coplan and Peter Goldie, 45–57. Oxford University Press, 2011. https://doi.org/10.1093/acprof:oso/9780199539956.003.0005.

Ickes, William. ‘Empathic Accuracy: Its Links to Clinical, Cognitive, Developmental, Social, and Physiological Psychology’. In *The Social Neuroscience of Empathy*, edited by Jean Decety and William Ickes, 57–70. The MIT Press, 2009. https://doi.org/10.7551/mitpress/9780262012973.003.0006.

Ishiguro, Nobu. ‘Care Robots in Japanese Elderly Care: Cultural Values in Focus’. In *The Routledge Handbook of Social Care Work Around the World*. Routledge, 2018.

Istituto Italiano di Tecnologia. ‘iCub History’. Istituto Italiano di Tecnologia iCub. Accessed 14 September 2023. https://icub.iit.it/web/icub/about-us/icub-history.

Ivanov, Stanislav, and Craig Webster. ‘Robots in Tourism: A Research Agenda for Tourism Economics’. *Tourism Economics* 26, no. 7 (1 November 2020): 1065–85. https://doi.org/10.1177/1354816619879583.

Jacob, K. S., P. Sharan, I. Mirza, M. Garrido-Cumbrera, S. Seedat, J. J. Mari, V. Sreenivas, and Shekhar Saxena. ‘Mental Health Systems in Countries: Where Are We Now?’ *The Lancet* 370, no. 9592 (22 September 2007): 1061–77. https://doi.org/10.1016/S0140-6736(07)61241-0.

Jacobs, Kerrin Artemis. ‘Digital Loneliness—Changes of Social Recognition through AI Companions’. *Frontiers in Digital Health* 6 (5 March 2024). https://doi.org/10.3389/fdgth.2024.1281037.

James, Jesin, Catherine Inez Watson, and Bruce MacDonald. ‘Artificial Empathy in Social Robots: An Analysis of Emotions in Speech’. In *2018 27th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*, 632–37, 2018. https://doi.org/10.1109/ROMAN.2018.8525652.

Jamison, Robert N., Winston C. V. Parris, and Wayne S. Maxson. ‘Psychological Factors Influencing Recovery from Outpatient Surgery’. *Behaviour Research and Therapy* 25, no. 1 (1 January 1987): 31–37. https://doi.org/10.1016/0005-7967(87)90112-4.

Jeong, Sooyeon, Cynthia Breazeal, Deirdre Logan, and Peter Weinstock. ‘Huggable: Impact of Embodiment on Promoting Verbal and Physical Engagement for Young Pediatric Inpatients’. In *2017 26th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*, 121–26, 2017. https://doi.org/10.1109/ROMAN.2017.8172290.

Johal, Wafa. ‘Research Trends in Social Robots for Learning’. *Current Robotics Reports* 1, no. 3 (1 September 2020): 75–83. https://doi.org/10.1007/s43154-020-00008-3.

Johnston, John. *The Allure of Machinic Life: Cybernetics, Artificial Life, and the New AI*. The MIT Press, 2008. https://doi.org/10.7551/mitpress/9780262101264.001.0001.

Jokinen, Kristiina, and Graham Wilcock. ‘Expectations and First Experience with a Social Robot’. *HAI*, 2017. https://doi.org/10.1145/3125739.3132610.

Kasneci, Enkelejda, Kathrin Sessler, Stefan Küchemann, Maria Bannert, Daryna Dementieva, Frank Fischer, Urs Gasser, et al. ‘ChatGPT for Good? On Opportunities and Challenges of Large Language Models for Education’. *Learning and Individual Differences* 103 (1 April 2023): 102274. https://doi.org/10.1016/j.lindif.2023.102274.

Kavaliers, Martin. ‘Evolutionary and Comparative Aspects of Nociception’. *Brain Research Bulletin* 21, no. 6 (1 December 1988): 923–31. https://doi.org/10.1016/0361-9230(88)90030-5.

Kaynak, Okyay. ‘The Golden Age of Artificial Intelligence’. *Discover Artificial Intelligence* 1, no. 1 (22 September 2021): 1. https://doi.org/10.1007/s44163-021-00009-x.

Keltner, Dacher, and Jonathan Haidt. ‘Social Functions of Emotions at Four Levels of Analysis’. *Cognition and Emotion* 13, no. 5 (1 September 1999): 505–21. https://doi.org/10.1080/026999399379168.

Kohonen, Teuvo. ‘Correlation Matrix Memories’. *IEEE Transactions on Computers* C–21, no. 4 (April 1972): 353–59. https://doi.org/10.1109/TC.1972.5008975.

Krause, Mark Andrew, Dan Dolderman, Stephen Smith, and Daniel Paul Corts. *An Introduction to Psychological Science: Modeling Scientific Literacy*. Pearson Education Canada, 2014.

Kwon, Minae, Malte F. Jung, and Ross A. Knepper. ‘Human Expectations of Social Robots’. In *2016 11th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, 463–64, 2016. https://doi.org/10.1109/HRI.2016.7451807.

Law, James, Mark Lee, Martin Hiilse, and Patricia Shaw. ‘Infants and iCubs: Applying Developmental Psychology to Robot Shaping’. *Procedia Computer Science*, Proceedings of the 2nd European Future Technologies Conference and Exhibition 2011 (FET 11), 7 (1 January 2011): 272–74. https://doi.org/10.1016/j.procs.2011.09.034.

LeDoux, Joseph. ‘The Amygdala’. *Current Biology* 17, no. 20 (2007): R868–74. https://doi.org/10.1016/j.cub.2007.08.005.

LeDoux, Joseph E. ‘The Amygdala: Contributions to Fear and Stress’. *Seminars in Neuroscience* 6, no. 4 (1 August 1994): 231–37. https://doi.org/10.1006/smns.1994.1030.

Lee, Mark. *How to Grow a Robot*. The MIT Press, 2020. https://mitpress.mit.edu/books/how-grow-robot.

Lee, Raymond S. T. *Artificial Intelligence in Daily Life*. Singapore: Springer, 2020. https://doi.org/10.1007/978-981-15-7695-9.

Lefkowitz, Melanie. ‘Professor’s Perceptron Paved the Way for AI – 60 Years Too Soon’. *Cornell Chronicle*, 25 September 2019. https://news.cornell.edu/stories/2019/09/professors-perceptron-paved-way-ai-60-years-too-soon.

Leite, Iolanda, Ginevra Castellano, André Pereira, Carlos Martinho, and Ana Paiva. ‘Empathic Robots for Long-Term Interaction’. *International Journal of Social Robotics* 6, no. 3 (1 August 2014): 329–41. https://doi.org/10.1007/s12369-014-0227-1.

Leite, Iolanda, Carlos Martinho, and Ana Paiva. ‘Social Robots for Long-Term Interaction: A Survey’. *International Journal of Social Robotics* 5, no. 2 (2013): 291–308.

Leonelli, Sabina. ‘Scientific Research and Big Data’. In *The Stanford Encyclopedia of Philosophy*, edited by Edward N. Zalta, Summer 2020. Metaphysics Research Lab, Stanford University, 2020. https://plato.stanford.edu/archives/sum2020/entries/science-big-data/.

Levenson, Robert W., Sandy J. Lwi, Casey L. Brown, Brett Q. Ford, Marcela C. Otero, and Alice Verstaen. ‘Emotion’. In *Handbook of Psychophysiology*, edited by Gary G. Berntson, John T. Cacioppo, and Louis G. Tassinary, 4th ed., 444–64. Cambridge Handbooks in Psychology. Cambridge: Cambridge University Press, 2016. https://doi.org/10.1017/9781107415782.020.

Lighthill, James. ‘Artificial Intelligence: A General Survey’. *Artificial Intelligence: A Paper Symposium*, 1973. https://www-formal.stanford.edu/jmc/reviews/lighthill/lighthill.html.

Lindquist, Kristen A. ‘Emotions Emerge from More Basic Psychological Ingredients: A Modern Psychological Constructionist Model’. *Emotion Review* 5, no. 4 (1 October 2013): 356–68. https://doi.org/10.1177/1754073913489750.

Lindquist, Kristen A., Tor D. Wager, Hedy Kober, Eliza Bliss-Moreau, and Lisa Feldman Barrett. ‘The Brain Basis of Emotion: A Meta-Analytic Review’. *Behavioral and Brain Sciences* 35, no. 3 (June 2012): 121–43. https://doi.org/10.1017/S0140525X11000446.

Luisi, Pier Luigi. ‘Autopoiesis: A Review and a Reappraisal’. *Naturwissenschaften* 90, no. 2 (1 February 2003): 49–59. https://doi.org/10.1007/s00114-002-0389-9.

Lungarella, Max, Fumiya Iida, Josh C. Bongard, and Rolf Pfeifer. ‘AI in the 21st Century – With Historical Reflections’. In *50 Years of Artificial Intelligence: Essays Dedicated to the 50th Anniversary of Artificial Intelligence*, edited by Max Lungarella, Fumiya Iida, Josh Bongard, and Rolf Pfeifer, 1–8. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer, 2007. https://doi.org/10.1007/978-3-540-77296-5\_1.

LuxAI S.A. ‘Qtrobot Curriculum for Autism’. Accessed 7 June 2024. https://luxai.com/qtrobot-curriculum-for-autism/.

Malle, Bertram, and Stuti Thapa. ‘What Kind of Mind Do I Want in My Robot?: Developing a Measure of Desired Mental Capacities in Social Robots’, 195–96, 2017. https://doi.org/10.1145/3029798.3038378.

Malsburg, Chr. von der. ‘Self-Organization of Orientation Sensitive Cells in the Striate Cortex’. *Kybernetik* 14, no. 2 (1 June 1973): 85–100. https://doi.org/10.1007/BF00288907.

Mar, Tanis, Vadim Tikhanoff, Giorgio Metta, and Lorenzo Natale. ‘Self-Supervised Learning of Grasp Dependent Tool Affordances on the iCub Humanoid Robot’, Vol. 2015, 2015. https://doi.org/10.1109/ICRA.2015.7139640.

Marocco, Davide, Angelo Cangelosi, Kerstin Fischer, and Tony Belpaeme. ‘Grounding Action Words in the Sensorimotor Interaction with the World: Experiments with a Simulated iCub Humanoid Robot’. *Frontiers in Neurorobotics* 4 (2010). https://www.frontiersin.org/articles/10.3389/fnbot.2010.00007.

Maron, Dina Fine. ‘What to Do If You’re Attacked by a Bear—or Any of These Other Wild Animals’. *Animals*, 17 August 2023. https://www.nationalgeographic.com/animals/article/survive-wildlife-encounters-bear-bison-shark-alligator.

Maturana, Humberto R., and Francisco J. Varela. *Autopoiesis and Cognition: The Realization of the Living*. Boston Studies in the Philosophy of Science. Dordrecht, Holland: D. Reidel Pub. Co., 1980.

McCorduck, P., M. Minsky, O. Selfridge, and H. A. Simon. ‘History of Artificial Intelligence’. In *Proceedings of the 5th International Joint Conference on Artificial Intelligence - Volume 2*, 951–54. IJCAI’77. San Francisco, CA, USA: Morgan Kaufmann Publishers Inc., 1977.

McCorduck, Pamela. *Machines Who Think: A Personal Inquiry Into the History and Prospects of Artificial Intelligence*. [2nd ed.]. Natick, Massachusetts: AK Peters, 2004.

Mehri, Nader, Mahmood Messkoub, and Suzanne Kunkel. ‘Trends, Determinants and the Implications of Population Aging in Iran’. *Ageing International* 45, no. 4 (1 December 2020): 327–43. https://doi.org/10.1007/s12126-020-09364-z.

Meskó, Bertalan, Gergely Hetényi, and Zsuzsanna Győrffy. ‘Will Artificial Intelligence Solve the Human Resource Crisis in Healthcare?’ *BMC Health Services Research* 18, no. 545 (13 July 2018). https://doi.org/10.1186/s12913-018-3359-4.

Mesoudi, Alex. ‘Cultural Evolution: A Review of Theory, Findings and Controversies’. *Evolutionary Biology* 43, no. 4 (1 December 2016): 481–97. https://doi.org/10.1007/s11692-015-9320-0.

Metta, Giorgio, Lorenzo Natale, Francesco Nori, Giulio Sandini, David Vernon, Luciano Fadiga, Claes von Hofsten, et al. ‘The iCub Humanoid Robot: An Open-Systems Platform for Research in Cognitive Development’. *Neural Networks*, Social Cognition: From Babies to Robots, 23, no. 8 (1 October 2010): 1125–34. https://doi.org/10.1016/j.neunet.2010.08.010.

Metta, Giorgio, Giulio Sandini, D. Vernon, Lorenzo Natale, and Francesco Nori. ‘iCub: The Open Humanoid Robot Designed for Learning and Developing Complex Cognitive Tasks’. *Proceedings of the 2019 IEEE RSJ International Conference on Intelligent Robots and Systems*, 2019.

Minsky, Marvin L. *Computation: Finite and Infinite Machines*. Englewood Cliffs, N.J.: Prentice-Hall, 1967.

MIT. ‘People Overview Cynthia Breazeal’. MIT Media Lab. Accessed 22 December 2023. https://www.media.mit.edu/people/cynthiab/overview/.

Montag, Christiane, Jürgen Gallinat, and Andreas Heinz. ‘Theodor Lipps and the Concept of Empathy: 1851–1914’. *American Journal of Psychiatry* 165, no. 10 (October 2008): 1261–1261. https://doi.org/10.1176/appi.ajp.2008.07081283.

Moor, James. ‘The Dartmouth College Artificial Intelligence Conference: The Next Fifty Years’. *AI Magazine* 27, no. 4 (2006): 87–91. https://doi.org/10.1609/aimag.v27i4.1911.

Moravec, Hans P. *Mind Children: The Future of Robot and Human Intelligence*. Cambridge, Mass: Harvard University Press, 1988.

———. *Robot: Mere Machine to Transcendent Mind*. New York: Oxford University Press, 1999.

Morse, Anthony, Joachim Greeff, Tony Belpaeme, and Angelo Cangelosi. ‘Epigenetic Robotics Architecture (ERA)’. *Autonomous Mental Development, IEEE Transactions On* 2 (1 January 2011): 325–39. https://doi.org/10.1109/TAMD.2010.2087020.

Moudatsou, Maria, Areti Stavropoulou, Anastas Philalithis, and Sofia Koukouli. ‘The Role of Empathy in Health and Social Care Professionals’. *Healthcare* 8, no. 1 (30 January 2020): 26. https://doi.org/10.3390/healthcare8010026.

Mueller, Bridget, Alex Figueroa, and Jessica Robinson-Papp. ‘Structural and Functional Connections Between the Autonomic Nervous System, Hypothalamic–Pituitary–Adrenal Axis, and the Immune System: A Context and Time Dependent Stress Response Network’. *Neurological Sciences* 43, no. 2 (1 February 2022): 951–60. https://doi.org/10.1007/s10072-021-05810-1.

Murari, Kartikeya, Ralph Etienne-Cummings, Nitish Thakor, and Gert Cauwenberghs. ‘Which Photodiode to Use: A Comparison of CMOS-Compatible Structures’. *IEEE Sensors Journal* 9, no. 7 (July 2009): 752–60. https://doi.org/10.1109/JSEN.2009.2021805.

Natale, Lorenzo, Ali Paikan, Marco Randazzo, and Daniele E. Domenichelli. ‘The iCub Software Architecture: Evolution and Lessons Learned’. *Frontiers in Robotics and AI* 3 (2016). https://www.frontiersin.org/articles/10.3389/frobt.2016.00024.

Nickerson, Raymond S., Susan F. Butler, and Michael Carlin. ‘Empathy and Knowledge Projection’. In *The Social Neuroscience of Empathy*, edited by Jean Decety and William Ickes, 43–56. The MIT Press, 2009. https://doi.org/10.7551/mitpress/9780262012973.003.0005.

Nilsson, Nils J. *The Quest for Artificial Intelligence*. Cambridge: Cambridge University Press, 2013. https://doi.org/10.1017/CBO9780511819346.

Oberman, Lindsay M., and V. S. Ramachandran. ‘Reflections on the Mirror Neuron System: Their Evolutionary Functions Beyond Motor Representation’. In *Mirror Neuron Systems: The Role of Mirroring Processes in Social Cognition*, edited by Jaime A. Pineda, 39–59. Contemporary Neuroscience. Totowa, NJ: Humana Press, 2009. https://doi.org/10.1007/978-1-59745-479-7\_2.

O’Connor, Jack. ‘Undercover Algorithm: A Secret Chapter in the Early History of Artificial Intelligence and Satellite Imagery’. *International Journal of Intelligence and CounterIntelligence* 0, no. 0 (21 June 2022): 1–15. https://doi.org/10.1080/08850607.2022.2073542.

Olaronke, Iroju, Ojerinde Oluwaseun, and Ikono Rhoda. ‘State Of The Art: A Study of Human-Robot Interaction in Healthcare’. *International Journal of Information Engineering and Electronic Business* 9, no. 3 (8 May 2017): 43–55. https://doi.org/10.5815/ijieeb.2017.03.06.

Olazaran, Mikel. ‘A Sociological Study of the Official History of the Perceptrons Controversy’. *Social Studies of Science* 26, no. 3 (1 August 1996): 611–59. https://doi.org/10.1177/030631296026003005.

OpenAI. ‘Sora: Creating Video from Text’. Accessed 27 February 2024. https://openai.com/sora.

O’Regan, Gerard. *A Brief History of Computing*. 2nd ed. London: Springer London, 2012. https://doi.org/10.1007/978-1-4471-2359-0.

Pantic, Maja, and Alessandro Vinciarelli. ‘Social Signal Processing’. In *The Oxford Handbook of Affective Computing*, 2015. https://doi.org/10.1093/oxfordhb/9780199942237.013.027.

Park, Sung, and Mincheol Whang. ‘Empathy in Human–Robot Interaction: Designing for Social Robots’. *International Journal of Environmental Research and Public Health* 19, no. 3 (8 February 2022): 1889. https://doi.org/10.3390/ijerph19031889.

Parker, Kim. ‘Family Support in Graying Societies’. *Pew Research Center’s Social & Demographic Trends Project* (blog), 21 May 2015. https://www.pewresearch.org/social-trends/2015/05/21/family-support-in-graying-societies/.

Parmiggiani, Alberto, Marco Maggiali, Lorenzo Natale, Francesco Nori, Alexander Schmitz, Nikos Tsagarakis, José Santos-Victor, Francesco Becchi, Giulio Sandini, and Giorgio Metta. ‘The Design of the iCub Humanoid Robot’. *International Journal of Humanoid Robotics* 9 (1 December 2012): 1–24. https://doi.org/10.1142/S0219843612500272.

Pedersen, Isabel, Samantha Reid, and Kristen Aspevig. ‘Developing Social Robots for Aging Populations: A Literature Review of Recent Academic Sources’. *Sociology Compass* 12, no. 6 (2018): e12585.

Pennisi, Paola, Alessandro Tonacci, Gennaro Tartarisco, Lucia Billeci, Liliana Ruta, Sebastiano Gangemi, and Giovanni Pioggia. ‘Autism and Social Robotics: A Systematic Review’. *Autism Research: Official Journal of the International Society for Autism Research* 9, no. 2 (February 2016): 165–83. https://doi.org/10.1002/aur.1527.

Pepito, Joseph Andrew, Hirokazu Ito, Feni Betriana, Tetsuya Tanioka, and Rozzano C. Locsin. ‘Intelligent Humanoid Robots Expressing Artificial Humanlike Empathy in Nursing Situations’. *Nursing Philosophy* 21, no. 4 (2020): e12318. https://doi.org/10.1111/nup.12318.

Pester, Patrick. ‘Humans Are Practically Defenseless. Why Don’t Wild Animals Attack Us More?’ *Livescience.Com* (blog), 12 July 2021. https://www.livescience.com/why-predators-dont-attack-humans.html.

Pfeifer, Jennifer, and Mirella Dapretto. ‘“Mirror, Mirror, in My Mind”: Empathy, Interpersonal Competence, and the Mirror Neuron System’, 183–98, 2009. https://doi.org/10.7551/mitpress/9780262012973.003.0015.

Phelps, Elizabeth A. ‘Emotion and Cognition: Insights from Studies of the Human Amygdala’. *Annual Review of Psychology* 57, no. 1 (2006): 27–53. https://doi.org/10.1146/annurev.psych.56.091103.070234.

Pitts, Walter. ‘Comments on Session on Learning Machines’. In *Proceedings of the March 1-3, 1955*, 108–11. AFIPS ’55 (Western). Los Angeles, CA: Association for Computing Machinery, 1955. https://doi.org/10.1145/1455292.1455313.

Plutchik, Robert. ‘Evolutionary Bases of Empathy’. In *Empathy and Its Development*, edited by Nancy Eisenberg and Janet Strayer, 38–46. Cambridge: Cambridge University Press, 1987.

Pohl, Martin. ‘Robotic Systems in Healthcare with Particular Reference to Innovation in the “Fourth Industrial Revolution”’ 8 (2016): 17–33.

Pollack, Jordan B., Hod Lipson, Gregory Hornby, and Pablo Funes. ‘Three Generations of Automatically Designed Robots’. *Artificial Life* 7, no. 3 (1 July 2001): 215–23. https://doi.org/10.1162/106454601753238627.

Porter, Richard E., and Larry A. Samovar. ‘Cultural Influences on Emotional Expression: Implications for Intercultural Communication’. In *Handbook of Communication and Emotion*, edited by Peter A. Andersen and Laura K. Guerrero, 451–72. San Diego: Academic Press, 1996. https://doi.org/10.1016/B978-012057770-5/50019-9.

Portner, Paul. *What Is Meaning? Fundamentals of Formal Semantics*. Fundamentals of Linguistics. Malden, MA: Blackwell Pub, 2005.

Prochazkova, Eliska, and Mariska E. Kret. ‘Connecting Minds and Sharing Emotions through Mimicry: A Neurocognitive Model of Emotional Contagion’. *Neuroscience & Biobehavioral Reviews* 80 (1 September 2017): 99–114. https://doi.org/10.1016/j.neubiorev.2017.05.013.

Quick, Oliver Santiago. ‘Empathizing and Sympathizing With Robots: Implications for Moral Standing’. *Frontiers in Robotics and AI* 8 (2022). https://www.frontiersin.org/articles/10.3389/frobt.2021.791527.

Raczaszek-Leonardi, Joanna, Iris Nomikou, and Katharina J. Rohlfing. ‘Young Children’s Dialogical Actions: The Beginnings of Purposeful Intersubjectivity’. *IEEE Transactions on Autonomous Mental Development* 5, no. 3 (September 2013): 210–21. https://doi.org/10.1109/TAMD.2013.2273258.

Revsbech, Jeppe Kiel. ‘When Humans and Robots Meet’. *School of Culture and Society News* (blog), 28 February 2022. https://cas.au.dk/en/currently/news/nyhedsarkiv/when-humans-and-robots-meet.

Ribas, Jordi. ‘Building the New Bing: Image Creator’. *Microsoft Bing Blogs* (blog), 23 March 2023. https://blogs.bing.com/search-quality-insights/march-2023/Building-the-New-Bing-Image-Creator/.

Robiner, William N. ‘The Mental Health Professions: Workforce Supply and Demand, Issues, and Challenges’. *Clinical Psychology Review* 26, no. 5 (1 September 2006): 600–625. https://doi.org/10.1016/j.cpr.2006.05.002.

Robinson, Nicole Lee, Timothy Vaughan Cottier, and David John Kavanagh. ‘Psychosocial Health Interventions by Social Robots: Systematic Review of Randomized Controlled Trials’. *Journal of Medical Internet Research* 21, no. 5 (10 May 2019): e13203. https://doi.org/10.2196/13203.

‘Robot’. In *Merriam-Webster.Com Dictionary*. Merriam-Webster. Accessed 23 February 2023. https://www.merriam-webster.com/dictionary/robot.

*Robot Self-Consciousness. XCR-1 Passes the Mirror Test*. Accessed 29 August 2024. https://youtube.com/watch?v=WE9QsQqsAdo.

*Robot Sequence Memory*, 2020. https://www.youtube.com/watch?v=8DNA6\_wKVJQ.

Rogers, Stephanie. ‘BRILLO the Bartending Robot Can Fulfill Your Social Needs While Slinging Cocktails’. *Dornob* (blog), 29 August 2022. https://dornob.com/brillo-the-bartending-robot-can-fulfill-your-social-needs-while-slinging-cocktails/.

Rojas, R. ‘Konrad Zuse’s Legacy: The Architecture of the Z1 and Z3’. *IEEE Annals of the History of Computing* 19, no. 2 (April 1997): 5–16. https://doi.org/10.1109/85.586067.

Rojas, Raúl, and Ulf Hashagen. ‘“Nothing New Since von Neumann”: A Historian Looks at Computer Architecture, 1945–1995’. In *The First Computers: History and Architectures*, 195–217. MIT Press, 2002. https://ieeexplore.ieee.org/document/6302806.

Rosenfeld, Edward. ‘Teuvo Kohonen’. In *Talking Nets: An Oral History of Neural Networks*, edited by James A. Andersen, and Edward Rosenfeld, 144–64. The MIT Press, 2000. https://direct.mit.edu/books/book/4886/chapter/622911/Teuvo-Kohonen.

Rowland, Donald T. ‘Global Population Aging: History and Prospects’. In *International Handbook of Population Aging*, edited by Peter Uhlenberg, 37–65. Dordrecht: Springer Netherlands, 2009. https://doi.org/10.1007/978-1-4020-8356-3\_3.

Russell, James A. ‘Core Affect and the Psychological Construction of Emotion’. *Psychological Review* 110, no. 1 (2003): 145–72. https://doi.org/10.1037/0033-295X.110.1.145.

———. ‘Emotion, Core Affect, and Psychological Construction’. *Cognition and Emotion* 23, no. 7 (1 November 2009): 1259–83. https://doi.org/10.1080/02699930902809375.

Russell, Stuart, and Peter Norvig. *Artificial Intelligence: A Modern Approach*. 3 edition. Upper Saddle River: Pearson, 2009.

Šabanović, Selma, Casey C. Bennett, Wan-Ling Chang, and Lesa Huber. ‘PARO Robot Affects Diverse Interaction Modalities in Group Sensory Therapy for Older Adults with Dementia’. In *2013 IEEE 13th International Conference on Rehabilitation Robotics (ICORR)*, 1–6, 2013. https://doi.org/10.1109/ICORR.2013.6650427.

Sandini, G., G. Metta, and D. Vernon. ‘RobotCub: An Open Framework for Research in Embodied Cognition’. In *4th IEEE/RAS International Conference on Humanoid Robots, 2004.*, 1:13-32 Vol. 1, 2004. https://doi.org/10.1109/ICHR.2004.1442111.

Sandini, Giulio, Giorgio Metta, and David Vernon. ‘The iCub Cognitive Humanoid Robot: An Open-System Research Platform for Enactive Cognition’. In *50 Years of Artificial Intelligence: Essays Dedicated to the 50th Anniversary of Artificial Intelligence*, edited by Max Lungarella, Fumiya Iida, Josh Bongard, and Rolf Pfeifer, 358–69. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer, 2007. https://doi.org/10.1007/978-3-540-77296-5\_32.

Scarantino, Andrea, and Paul Griffiths. ‘Don’t Give Up on Basic Emotions’. *Emotion Review* 3, no. 4 (1 October 2011): 444–54. https://doi.org/10.1177/1754073911410745.

Scarantino, Andrea, and Ronald de Sousa. ‘Emotion’. In *The Stanford Encyclopedia of Philosophy*, edited by Edward N. Zalta, Summer 2021. Metaphysics Research Lab, Stanford University, 2021. https://plato.stanford.edu/archives/sum2021/entries/emotion/.

Scassellati, Brian, Henny Admoni, and Maja Matarić. ‘Robots for Use in Autism Research’. *Annual Review of Biomedical Engineering* 14, no. 1 (2012): 275–94. https://doi.org/10.1146/annurev-bioeng-071811-150036.

Schertz, Matthew Victor. ‘Empathy as Intersubjectivity: Resolving Hume and Smith’s Divide’. *Studies in Philosophy and Education* 26, no. 2 (1 March 2007): 165–78. https://doi.org/10.1007/s11217-006-9022-2.

Schidelko, Lydia P., Michael Huemer, Lara M. Schröder, Anna S. Lueb, Josef Perner, and Hannes Rakoczy. ‘Why Do Children Who Solve False Belief Tasks Begin to Find True Belief Control Tasks Difficult? A Test of Pragmatic Performance Factors in Theory of Mind Tasks’. *Frontiers in Psychology* 12 (14 January 2022). https://doi.org/10.3389/fpsyg.2021.797246.

Schimmack, Ulrich, and Alexander Grob. ‘Dimensional Models of Core Affect: A Quantitative Comparison by Means of Structural Equation Modeling’. *European Journal of Personality* 14, no. 4 (2000): 325–45. https://doi.org/10.1002/1099-0984(200007/08)14:4<325::AID-PER380>3.0.CO;2-I.

Scoglio, Arielle AJ, Erin D. Reilly, Jay A. Gorman, and Charles E. Drebing. ‘Use of Social Robots in Mental Health and Well-Being Research: Systematic Review’. *Journal of Medical Internet Research* 21, no. 7 (24 July 2019): e13322. https://doi.org/10.2196/13322.

Seibt, Johanna. ‘Towards an Ontology of Simulated Social Interaction: Varieties of the “As If” for Robots and Humans’. In *Sociality and Normativity for Robots: Philosophical Inquiries into Human-Robot Interactions*, edited by Raul Hakli and Johanna Seibt, 11–39. Studies in the Philosophy of Sociality. Cham: Springer International Publishing, 2017. https://doi.org/10.1007/978-3-319-53133-5\_2.

Sejnowski, Terrence J. *The Deep Learning Revolution*. The MIT Press, 2018. https://doi.org/10.7551/mitpress/11474.001.0001.

———. *The Deep Learning Revolution*. Cambridge, Massachusetts: MIT Press, 2018. https://mitpress.mit.edu/9780262038034/the-deep-learning-revolution/.

Shamay-Tsoory, Simone G. ‘Empathic Processing: Its Cognitive and Affective Dimensions and Neuroanatomical Basis’. In *The Social Neuroscience of Empathy*, edited by Jean Decety and William Ickes, 215–32. The MIT Press, 2009. https://doi.org/10.7551/mitpress/9780262012973.003.0017.

Shannon, Claude E. ‘Programming a Computer for Playing Chess’. *Philosophical Magazine*, 7, 41, no. 314 (1 March 1950): 256–75. https://doi.org/10.1080/14786445008521796.

Shapiro, Lawrence, and Shannon Spaulding. ‘Embodied Cognition’. In *The Stanford Encyclopedia of Philosophy*, edited by Edward N. Zalta, Winter 2021. Metaphysics Research Lab, Stanford University, 2021. https://plato.stanford.edu/archives/win2021/entries/embodied-cognition/.

Sharkey, Amanda, and Noel Sharkey. ‘Granny and the Robots: Ethical Issues in Robot Care for the Elderly’. *Ethics and Information Technology* 14, no. 1 (1 March 2012): 27–40. https://doi.org/10.1007/s10676-010-9234-6.

Shaw, Patricia, James Law, and Mark Lee. ‘Representations of Body Schemas for Infant Robot Development’. In *2015 Joint IEEE International Conference on Development and Learning and Epigenetic Robotics (ICDL-EpiRob)*, 123–28, 2015. https://doi.org/10.1109/DEVLRN.2015.7346128.

Shibata, Takanori. ‘Therapeutic Seal Robot as Biofeedback Medical Device: Qualitative and Quantitative Evaluations of Robot Therapy in Dementia Care’. *Proceedings of the IEEE* 100, no. 8 (August 2012): 2527–38. https://doi.org/10.1109/JPROC.2012.2200559.

Siegler, Robert S., Judy S. DeLoache, and Nancy Eisenberg. *How Children Develop*. Fourth Canadian Edition. Macmillan, 2014.

Singer, Stephen. ‘With Endless Patience and Never Tiring, Robots Are Being Used in Connecticut to Connect with Children with Autism’. *Hartford Courant*, 28 August 2022. https://www.courant.com/news/connecticut/hc-news-robotics-autistic-children-20220828-tvmcwygg45eltmmfqzy24nibqu-story.html.

Snell, K. D. M. ‘The Rise of Living Alone and Loneliness in History’. *Social History* 42, no. 1 (2 January 2017): 2–28. https://doi.org/10.1080/03071022.2017.1256093.

Stano, Pasquale, Chrystopher Nehaniv, Takashi Ikegami, Luisa Damiano, and Olaf Witkowski. ‘Autopoiesis: Foundations of Life, Cognition, and Emergence of Self/Other’. *Biosystems* 232 (1 October 2023): 105008. https://doi.org/10.1016/j.biosystems.2023.105008.

Steels, Luc. ‘Fifty Years of AI: From Symbols to Embodiment - and Back’. In *50 Years of Artificial Intelligence: Essays Dedicated to the 50th Anniversary of Artificial Intelligence*, edited by Max Lungarella, Fumiya Iida, Josh Bongard, and Rolf Pfeifer, 18–28. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer, 2007. https://doi.org/10.1007/978-3-540-77296-5\_3.

Stein, Edith. *On the Problem of Empathy*. Dordrecht: Springer Netherlands, 1964. https://doi.org/10.1007/978-94-017-5546-7.

Stone, Robyn, and Mary F. Harahan. ‘Improving The Long-Term Care Workforce Serving Older Adults’. *Health Affairs* 29, no. 1 (January 2010): 109–15. https://doi.org/10.1377/hlthaff.2009.0554.

Stueber, Karsten. ‘Empathy’. In *The Stanford Encyclopedia of Philosophy*, edited by Edward N. Zalta, Fall 2019. Metaphysics Research Lab, Stanford University, 2019. https://plato.stanford.edu/archives/fall2019/entries/empathy/.

Stueber, Karsten R. *Rediscovering Empathy: Agency, Folk Psychology, and the Human Sciences*. The MIT Press, 2006. https://www.jstor.org/stable/j.ctt5hhbjr.

Sun, Ron. ‘Connectionism and Neural Networks’. In *The Cambridge Handbook of Artificial Intelligence*, edited by Keith Frankish and William M. Ramsey, 108–27. Cambridge: Cambridge University Press, 2014. https://doi.org/10.1017/CBO9781139046855.008.

Surkalim, Daniel L., Mengyun Luo, Robert Eres, Klaus Gebel, Joseph van Buskirk, Adrian Bauman, and Ding Ding. ‘The Prevalence of Loneliness across 113 Countries: Systematic Review and Meta-Analysis’. *BMJ* 376 (9 February 2022): e067068. https://doi.org/10.1136/bmj-2021-067068.

Suzuki, Toru. *Low Fertility and Population Aging in Japan and Eastern Asia*. SpringerBriefs in Population Studies. Tokyo: Springer Japan, 2013. https://doi.org/10.1007/978-4-431-54780-8.

Tanevska, Ana, Francesco Rea, Giulio Sandini, Lola Cañamero, and Alessandra Sciutti. ‘A Cognitive Architecture for Socially Adaptable Robots’. In *2019 Joint IEEE 9th International Conference on Development and Learning and Epigenetic Robotics (ICDL-EpiRob)*, 195–200, 2019. https://doi.org/10.1109/DEVLRN.2019.8850688.

Tanevska, Ana, Francesco Rea, Giulio Sandini, and Alessandra Sciutti. ‘Towards an Affective Cognitive Architecture for Human-Robot Interaction for the iCub Robot’, 2017. https://inria.hal.science/hal-01615491.

TenHouten, Warren D. ‘Basic Emotion Theory, Social Constructionism, and the Universal Ethogram’. *Social Science Information* 60, no. 4 (1 December 2021): 610–30. https://doi.org/10.1177/05390184211046481.

‘The Orocos Project’. Accessed 19 September 2023. https://orocos.org/.

Thomaz, Andrea, Guy Hoffman, and Maya Cakmak. ‘Computational Human-Robot Interaction’. *Foundations and Trends in Robotics* 4, no. 2–3 (20 December 2016): 105–223. https://doi.org/10.1561/2300000049.

Thompson, Evan. *Mind in Life: Biology, Phenomenology, and the Sciences of Mind a Book by Evan Thompson*. Cambridge, Massachusetts: The Belknap Press of Harvard University Press, 2007.

———. ‘Sensorimotor Subjectivity and the Enactive Approach to Experience’. *Phenomenology and the Cognitive Sciences* 4, no. 4 (1 December 2005): 407–27. https://doi.org/10.1007/s11097-005-9003-x.

Thunberg, Sofia, and Tom Ziemke. ‘Are People Ready for Social Robots in Public Spaces?’ In *Companion of the 2020 ACM/IEEE International Conference on Human-Robot Interaction*, 482–84. HRI ’20. New York, NY, USA: Association for Computing Machinery, 2020. https://doi.org/10.1145/3371382.3378294.

Tikhanoff, V., A. Cangelosi, P. Fitzpatrick, G. Metta, L. Natale, and F. Nori. ‘An Open-Source Simulator for Cognitive Robotics Research: The Prototype of the iCub Humanoid Robot Simulator’. In *Proceedings of the 8th Workshop on Performance Metrics for Intelligent Systems*, 57–61. PerMIS ’08. New York, NY, USA: Association for Computing Machinery, 2008. https://doi.org/10.1145/1774674.1774684.

Tikhanoff, Vadim, Angelo Cangelosi, and Giorgio Metta. ‘Integration of Speech and Action in Humanoid Robots: iCub Simulation Experiments’. *IEEE Transactions on Autonomous Mental Development* 3, no. 1 (March 2011): 17–29. https://doi.org/10.1109/TAMD.2010.2100390.

Tomasello, Michael, and Ann Cale Kruger. ‘Joint Attention on Actions: Acquiring Verbs in Ostensive and Non-Ostensive Contexts\*’. *Journal of Child Language* 19, no. 2 (June 1992): 311–33. https://doi.org/10.1017/S0305000900011430.

Tremblay, Marie-Pier B., Isabelle Deschamps, Béatrice Tousignant, and Philip L. Jackson. ‘Functional Connectivity Patterns of Trait Empathy Are Associated with Age’. *Brain and Cognition* 159 (1 June 2022): 105859. https://doi.org/10.1016/j.bandc.2022.105859.

Tsigos, Constantine, and George P Chrousos. ‘Hypothalamic–Pituitary–Adrenal Axis, Neuroendocrine Factors and Stress’. *Journal of Psychosomatic Research* 53, no. 4 (1 October 2002): 865–71. https://doi.org/10.1016/S0022-3999(02)00429-4.

Turing, Alan M. ‘Computing Machinery and Intelligence.’ *Mind* 49 (1950): 433–60.

Turkle, Sherry. *The Second Self: Computers and the Human Spirit*, 2005. https://doi.org/10.7551/mitpress/6115.001.0001.

Uhlenberg, Peter, ed. *International Handbook of Population Aging*. International Handbooks of Population 1. Springer, 2009. 10.1007/978-1-4020-8356-3.

University of Illinois Springfield Philosophy Department. ‘Faculty & Staff’. Accessed 29 August 2024. https://www.uis.edu/philosophy/faculty-staff.

Vallverdú, Jordi, and David Casacuberta. ‘Ethical and Technical Aspects of Emotions to Create Empathy in Medical Machines’. In *Machine Medical Ethics*, edited by Simon Peter van Rysewyk and Matthijs Pontier, 341–62. Intelligent Systems, Control and Automation: Science and Engineering. Cham: Springer International Publishing, 2015. https://doi.org/10.1007/978-3-319-08108-3\_20.

Varela, F. G., H. R. Maturana, and R. Uribe. ‘Autopoiesis: The Organization of Living Systems, Its Characterization and a Model’. *Biosystems* 5, no. 4 (1 May 1974): 187–96. https://doi.org/10.1016/0303-2647(74)90031-8.

Varela, Francisco J. *Principles of Biological Autonomy*. North Holland Series in General Systems Research 2. New York : North Holland, 1979: New York : North Holland, 1979.

Varela, Francisco J., Eleanor Rosch, and Evan Thompson. *The Embodied Mind: Cognitive Science and Human Experience*. The MIT Press, 1991. https://doi.org/10.7551/mitpress/6730.001.0001.

Vercelli, Alessandro, Innocenzo Rainero, Ludovico Ciferri, Marina Boido, and Fabrizio Pirri. ‘Robots in Elderly Care’. *DigitCult - Scientific Journal on Digital Cultures* 2, no. 2 (6 March 2018): 37–50. https://doi.org/10.4399/97888255088954.

Vernon, David, and Dermot Furlong. ‘Philosophical Foundations of AI’. In *50 Years of Artificial Intelligence: Essays Dedicated to the 50th Anniversary of Artificial Intelligence*, edited by Max Lungarella, Fumiya Iida, Josh Bongard, and Rolf Pfeifer, 53–62. Berlin, Heidelberg: Springer, 2007. https://doi.org/10.1007/978-3-540-77296-5\_6.

Vernon, David, Giorgio Metta, and Giulio Sandini. ‘The iCub Cognitive Architecture: Interactive Development in a Humanoid Robot’. In *2007 IEEE 6th International Conference on Development and Learning*, 122–27, 2007. https://doi.org/10.1109/DEVLRN.2007.4354038.

Waal, Frans B. M. de. ‘Empathy in Primates and Other Mammals’. In *Empathy: From Bench to Bedside*, edited by Jean Decety, 87–106. The MIT Press, 2011. https://doi.org/10.7551/mitpress/9780262016612.003.0006.

Waal, Frans B. M. de, and Stephanie D. Preston. ‘Mammalian Empathy: Behavioural Manifestations and Neural Basis’. *Nature Reviews Neuroscience* 18, no. 8 (August 2017): 498–509. https://doi.org/10.1038/nrn.2017.72.

Waltz, Emily. ‘Therapy Robot Teaches Social Skills to Children With Autism’. *IEEE Spectrum*, 9 August 2018. https://spectrum.ieee.org/robot-therapy-for-autism.

Wang, Philip S., Sergio Aguilar-Gaxiola, Jordi Alonso, Matthias C. Angermeyer, Guilherme Borges, Evelyn J. Bromet, Ronny Bruffaerts, et al. ‘Use of Mental Health Services for Anxiety, Mood, and Substance Disorders in 17 Countries in the WHO World Mental Health Surveys’. *The Lancet* 370, no. 9590 (8 September 2007): 841–50. https://doi.org/10.1016/S0140-6736(07)61414-7.

Warneken, Felix, and Michael Tomasello. ‘Altruistic Helping in Human Infants and Young Chimpanzees’. *Science* 311, no. 5765 (3 March 2006): 1301–3. https://doi.org/10.1126/science.1121448.

———. ‘Extrinsic Rewards Undermine Altruistic Tendencies in 20-Month-Olds’. *Developmental Psychology* 44, no. 6 (2008): 1785–88. https://doi.org/0.1037/a0013860.

Watson, David S. ‘On the Philosophy of Unsupervised Learning’. *Philosophy & Technology* 36, no. 2 (21 April 2023): 28. https://doi.org/10.1007/s13347-023-00635-6.

Waytz, Adam, Kurt Gray, Nicholas Epley, and Daniel M. Wegner. ‘Causes and Consequences of Mind Perception’. *Trends in Cognitive Sciences* 14, no. 8 (1 August 2010): 383–88. https://doi.org/10.1016/j.tics.2010.05.006.

Waytz, Adam, Carey Morewedge, Nicholas Epley, George Monteleone, Jia-Hong Gao, and John Cacioppo. ‘Making Sense by Making Sentient: Effectance Motivation Increases Anthropomorphism’. *Journal of Personality and Social Psychology* 99 (1 September 2010): 410–35. https://doi.org/10.1037/a0020240.

Weizenbaum, Joseph. *Computer Power and Human Reason: From Judgment to Calculation*. 1st edition. San Francisco: W H Freeman & Co, 1976.

———. ‘ELIZA—A Computer Program For the Study of Natural Language Communication Between Man And Machine’. Edited by A.G. Oettinger. *Communications of the ACM* 9, no. 1 (January 1966): 36–45. https://doi.org/10.1145/365153.365168.

Wheeler, Michael. ‘Martin Heidegger’. In *The Stanford Encyclopedia of Philosophy*, edited by Edward N. Zalta, Fall 2020. Metaphysics Research Lab, Stanford University, 2020. https://plato.stanford.edu/archives/fall2020/entries/heidegger/.

Wiener, Norbert. *Cybernetics or Control and Communication in the Animal and the Machine*. Second. Cambridge, MA: The MIT Press, 1948. https://doi.org/10.7551/mitpress/11810.001.0001.

———. *The Human Use of Human Beings: Cybernetics and Society*. 2d ed. rev. Garden City, NY: Doubleday, 1954.

Williams, M.R. ‘The Origins, Uses, and Fate of the EDVAC’. *IEEE Annals of the History of Computing* 15, no. 1 (1993): 22–38. https://doi.org/10.1109/85.194089.

Winkielman, Piotr, Joshua D. Davis, and Seana Coulson. ‘Moving Thoughts: Emotion Concepts from the Perspective of Context Dependent Embodied Simulation’. *Language, Cognition and Neuroscience* 38, no. 10 (26 November 2023): 1531–53. https://doi.org/10.1080/23273798.2023.2236731.

Wirtz, Jochen, Werner Kunz, and Stefanie Paluch. ‘The Service Revolution, Intelligent Automation and Service Robots’. *European Business Review* 29, no. 5 (2021): 909.

Wispé, Lauren. ‘History of the Concept of Empathy’. In *Empathy and Its Development*, edited by Nancy Eisenberg and Janet Strayer, 17–37. Cambridge: Cambridge University Press, 1987.

Wooldridge, Michael. *A Brief History of Artificial Intelligence: What It Is, Where We Are, and Where We Are Going*. New York: Flatiron Books, 2020. https://us.macmillan.com/books/9781250770738/abriefhistoryofartificialintelligence.

Wright, James. ‘Inside Japan’s Long Experiment in Automating Elder Care’. *MIT Technology Review* (blog), 9 January 2023. https://www.technologyreview.com/2023/01/09/1065135/japan-automating-eldercare-robots/.

Young, Rupert. ‘A General Architecture for Robotics Systems: A Perception-Based Approach to Artificial Life’. *Artificial Life* 23, no. 2 (1 May 2017): 236–86. https://doi.org/10.1162/ARTL\_a\_00229.

YouTube. ‘Pentti Haikonen’. Accessed 6 March 2024. https://www.youtube.com/@PenHaiko.

Yu, Ruby, Elsie Hui, Jenny Lee, Dawn Poon, Ashley Ng, Kitty Sit, Kenny Ip, et al. ‘Use of a Therapeutic, Socially Assistive Pet Robot (PARO) in Improving Mood and Stimulating Social Interaction and Communication for People With Dementia: Study Protocol for a Randomized Controlled Trial’. *JMIR Research Protocols* 4, no. 2 (1 May 2015): e45. https://doi.org/10.2196/resprot.4189.

Zahavi, Dan. ‘Empathy and Other-Directed Intentionality’. *Topoi* 33, no. 1 (2014): 129–42. https://doi.org/10.1007/s11245-013-9197-4.

Zahavi, Dan, and Philippe Rochat. ‘Empathy≠sharing: Perspectives from Phenomenology and Developmental Psychology’. *Consciousness and Cognition* 36 (1 November 2015): 543–53. https://doi.org/10.1016/j.concog.2015.05.008.

Ziemke, Tom. ‘The Body of Knowledge: On the Role of the Living Body in Grounding Embodied Cognition’. *Biosystems* 148, no. Complete (2016): 4–11. https://doi.org/10.1016/j.biosystems.2016.08.005.

1. Seibt, ‘Towards an Ontology of Simulated Social Interaction’, 12. [↑](#footnote-ref-2)
2. ‘Robot’; Bhaumik, *From AI to Robotics*, 4. [↑](#footnote-ref-3)
3. Campa, ‘The Rise of Social Robots’, 107. [↑](#footnote-ref-4)
4. Suzuki, *Low Fertility and Population Aging in Japan and Eastern Asia*, 4. [↑](#footnote-ref-5)
5. Suzuki, *Low Fertility and Population Aging in Japan and Eastern Asia*. [↑](#footnote-ref-6)
6. Suzuki, 70. [↑](#footnote-ref-7)
7. Suzuki, 2. [↑](#footnote-ref-8)
8. Wright, ‘Inside Japan’s Long Experiment in Automating Elder Care’. [↑](#footnote-ref-9)
9. Broekens, Heerink, and Rosendal, ‘Assistive Social Robots in Elderly Care’, 94; Čaić, Mahr, and Oderkerken-Schröder, ‘Value of Social Robots in Services’, 464; Pedersen, Reid, and Aspevig, ‘Developing Social Robots for Aging Populations’, 2. [↑](#footnote-ref-10)
10. Pedersen, Reid, and Aspevig, ‘Developing Social Robots for Aging Populations’, 8; Pohl, ‘Robotic Systems in Healthcare with Particular Reference to Innovation in the “Fourth Industrial Revolution”’, 20. [↑](#footnote-ref-11)
11. Ishiguro, ‘Care Robots in Japanese Elderly Care’, 256. [↑](#footnote-ref-12)
12. Ishiguro, 257–58. [↑](#footnote-ref-13)
13. Yu et al., ‘Use of a Therapeutic, Socially Assistive Pet Robot (PARO) in Improving Mood and Stimulating Social Interaction and Communication for People With Dementia’; Sharkey and Sharkey, ‘Granny and the Robots’, 35. [↑](#footnote-ref-14)
14. Šabanović et al., ‘PARO Robot Affects Diverse Interaction Modalities in Group Sensory Therapy for Older Adults with Dementia’, 5; Shibata, ‘Therapeutic Seal Robot as Biofeedback Medical Device’, 2527. [↑](#footnote-ref-15)
15. Scoglio et al., ‘Use of Social Robots in Mental Health and Well-Being Research’. [↑](#footnote-ref-16)
16. Horowitz, ‘Who Will Take Care of Italy’s Older People?’; Parker, ‘Family Support in Graying Societies’. [↑](#footnote-ref-17)
17. Uhlenberg, *International Handbook of Population Aging*, 1. [↑](#footnote-ref-18)
18. Feng et al., ‘China’s Rapidly Aging Population Creates Policy Challenges In Shaping A Viable Long-Term Care System’, 2764. [↑](#footnote-ref-19)
19. Chatterji et al., ‘The Health Of Aging Populations In China And India’, 1052. [↑](#footnote-ref-20)
20. Mehri, Messkoub, and Kunkel, ‘Trends, Determinants and the Implications of Population Aging in Iran’, 327. [↑](#footnote-ref-21)
21. Chawla, Betcherman, and Banerji, *From Red to Gray*, 1–2. [↑](#footnote-ref-22)
22. Henderson, Maniam, and Leavell, ‘The Silver Tsunami’, 153. [↑](#footnote-ref-23)
23. Czaja and Ceruso, ‘The Promise of Artificial Intelligence in Supporting an Aging Population’, 183. [↑](#footnote-ref-24)
24. Meskó, Hetényi, and Győrffy, ‘Will Artificial Intelligence Solve the Human Resource Crisis in Healthcare?’, 1; Olaronke, Oluwaseun, and Rhoda, ‘State Of The Art’, 43. [↑](#footnote-ref-25)
25. Rowland, ‘Global Population Aging’, 48; Colombo and Mercier, ‘Help Wanted!’, 3. [↑](#footnote-ref-26)
26. Chen et al., ‘Human Resources for Health’, 1985–86; Stone and Harahan, ‘Improving The Long-Term Care Workforce Serving Older Adults’, 109; Pohl, ‘Robotic Systems in Healthcare with Particular Reference to Innovation in the “Fourth Industrial Revolution”’, 20. [↑](#footnote-ref-27)
27. Vercelli et al., ‘Robots in Elderly Care’, 38. [↑](#footnote-ref-28)
28. González-González, Violant-Holz, and Gil-Iranzo, ‘Social Robots in Hospitals’; Aymerich-Franch, ‘Why It Is Time to Stop Ostracizing Social Robots’, 364. [↑](#footnote-ref-29)
29. Wirtz, Kunz, and Paluch, ‘The Service Revolution, Intelligent Automation and Service Robots’, 41. [↑](#footnote-ref-30)
30. Jamison, Parris, and Maxson, ‘Psychological Factors Influencing Recovery from Outpatient Surgery’, 36. [↑](#footnote-ref-31)
31. Feingold Polak and Tzedek, ‘Social Robot for Rehabilitation’, 157. [↑](#footnote-ref-32)
32. Cifuentes et al., ‘Social Robots in Therapy and Care’, 67; Jeong et al., ‘Huggable’, 125. [↑](#footnote-ref-33)
33. Ghafurian, Ellard, and Dautenhahn, ‘Social Companion Robots to Reduce Isolation’, 43. [↑](#footnote-ref-34)
34. Snell, ‘The Rise of Living Alone and Loneliness in History’, 22. [↑](#footnote-ref-35)
35. Hu, ‘A Design of Service Robots in Epidemic Disease Isolation Environment’, 12. [↑](#footnote-ref-36)
36. Ghafurian, Ellard, and Dautenhahn, ‘Social Companion Robots to Reduce Isolation’, 43. [↑](#footnote-ref-37)
37. Jacob et al., ‘Mental Health Systems in Countries’, 1061; Wang et al., ‘Use of Mental Health Services for Anxiety, Mood, and Substance Disorders in 17 Countries in the WHO World Mental Health Surveys’, 846; Robiner, ‘The Mental Health Professions’, 601. [↑](#footnote-ref-38)
38. Guemghar et al., ‘Social Robot Interventions in Mental Health Care and Their Outcomes, Barriers, and Facilitators’, e36094; Scoglio et al., ‘Use of Social Robots in Mental Health and Well-Being Research’, 13322. [↑](#footnote-ref-39)
39. Robinson, Cottier, and Kavanagh, ‘Psychosocial Health Interventions by Social Robots’, e13203. [↑](#footnote-ref-40)
40. Belpaeme et al., ‘Social Robots for Education’, 7; Edwards and Cheok, ‘Why Not Robot Teachers’, 349; Johal, ‘Research Trends in Social Robots for Learning’, 81. [↑](#footnote-ref-41)
41. Dautenhahn, ‘Roles and Functions of Robots in Human Society’, 446. [↑](#footnote-ref-42)
42. ‘Qtrobot Curriculum for Autism’. [↑](#footnote-ref-43)
43. Dautenhahn, ‘Roles and Functions of Robots in Human Society’, 446. [↑](#footnote-ref-44)
44. Cabibihan et al., ‘Why Robots?’, 614; Waltz, ‘Therapy Robot Teaches Social Skills to Children With Autism’. [↑](#footnote-ref-45)
45. Huijnen, AS Lexis, and de Witte, ‘Robots as New Tools in Therapy and Education for Children with Autism’, 3. [↑](#footnote-ref-46)
46. Singer, ‘With Endless Patience and Never Tiring, Robots Are Being Used in Connecticut to Connect with Children with Autism’. [↑](#footnote-ref-47)
47. Pennisi et al., ‘Autism and Social Robotics’, 178; Scassellati, Admoni, and Matarić, ‘Robots for Use in Autism Research’, 289. [↑](#footnote-ref-48)
48. Diehl et al., ‘The Clinical Use of Robots for Individuals with Autism Spectrum Disorders’, 255. [↑](#footnote-ref-49)
49. Scassellati, Admoni, and Matarić, ‘Robots for Use in Autism Research’, 278. [↑](#footnote-ref-50)
50. Cabibihan et al., ‘Why Robots?’, 615. [↑](#footnote-ref-51)
51. Thunberg and Ziemke, ‘Are People Ready for Social Robots in Public Spaces?’, 482. [↑](#footnote-ref-52)
52. Ivanov and Webster, ‘Robots in Tourism’, 1065. [↑](#footnote-ref-53)
53. Rogers, ‘BRILLO the Bartending Robot Can Fulfill Your Social Needs While Slinging Cocktails’. [↑](#footnote-ref-54)
54. Hegel et al., ‘Understanding Social Robots’, 171. [↑](#footnote-ref-55)
55. Beer et al., ‘Affective Human–Robot Interaction’, 361; Forgas-Coll et al., ‘How Do Consumers’ Gender and Rational Thinking Affect the Acceptance of Entertainment Social Robots?’, 14. [↑](#footnote-ref-56)
56. Hegel et al., ‘Understanding Social Robots’, 170. [↑](#footnote-ref-57)
57. Leite et al., ‘Empathic Robots for Long-Term Interaction’, 329; Malle and Thapa, ‘What Kind of Mind Do I Want in My Robot?’, 196. [↑](#footnote-ref-58)
58. de Graaf and Ben Allouch, ‘Exploring Influencing Variables for the Acceptance of Social Robots’, 1485. [↑](#footnote-ref-59)
59. Gompei and Umemuro, ‘Factors and Development of Cognitive and Affective Trust on Social Robots’, 51. [↑](#footnote-ref-60)
60. Leite et al., ‘Empathic Robots for Long-Term Interaction’, 330. [↑](#footnote-ref-61)
61. Leite, Martinho, and Paiva, ‘Social Robots for Long-Term Interaction’, 297. [↑](#footnote-ref-62)
62. Leite, Martinho, and Paiva, 300. [↑](#footnote-ref-63)
63. Jokinen and Wilcock, ‘Expectations and First Experience with a Social Robot’, 514. [↑](#footnote-ref-64)
64. Kwon, Jung, and Knepper, ‘Human Expectations of Social Robots’, 463. [↑](#footnote-ref-65)
65. Thomaz, Hoffman, and Cakmak, ‘Computational Human-Robot Interaction’, 122. [↑](#footnote-ref-66)
66. Pantic and Vinciarelli, ‘Social Signal Processing’, 144; Esposito and Jain, ‘Modeling Social Signals and Contexts in Robotic Socially Believable Behaving Systems’, 6; Hegel et al., ‘Understanding Social Robots’, 172. [↑](#footnote-ref-67)
67. Pantic and Vinciarelli, ‘Social Signal Processing’, 148; Thomaz, Hoffman, and Cakmak, ‘Computational Human-Robot Interaction’, 134. [↑](#footnote-ref-68)
68. Portner, *What Is Meaning?*, 94. [↑](#footnote-ref-69)
69. Esposito and Jain, ‘Modeling Social Signals and Contexts in Robotic Socially Believable Behaving Systems’, 6; Thomaz, Hoffman, and Cakmak, ‘Computational Human-Robot Interaction’, 126. [↑](#footnote-ref-70)
70. Raczaszek-Leonardi, Nomikou, and Rohlfing, ‘Young Children’s Dialogical Actions’, 212–13. [↑](#footnote-ref-71)
71. Clodic et al., ‘Key Elements for Human-Robot Joint Action’, 164. [↑](#footnote-ref-72)
72. Tomasello and Kruger, ‘Joint Attention on Actions’, 312–13. [↑](#footnote-ref-73)
73. Clodic et al., ‘Key Elements for Human-Robot Joint Action’, 168. [↑](#footnote-ref-74)
74. Clodic et al., 169. [↑](#footnote-ref-75)
75. Hakli and Seibt, ‘“Sociality and Normativity for Robots”’, 2. [↑](#footnote-ref-76)
76. ‘Johanna Seibt’; Revsbech, ‘When Humans and Robots Meet’. [↑](#footnote-ref-77)
77. Seibt, ‘Towards an Ontology of Simulated Social Interaction’, 14. [↑](#footnote-ref-78)
78. Seibt, 36. [↑](#footnote-ref-79)
79. Seibt, 37. [↑](#footnote-ref-80)
80. Turkle, *The Second Self*, 57; Waytz et al., ‘Making Sense by Making Sentient’, 423; Waytz et al., ‘Causes and Consequences of Mind Perception’, 384. [↑](#footnote-ref-81)
81. Bickhard, ‘Robot Sociality’, 62. [↑](#footnote-ref-82)
82. Depounti, Saukko, and Natale, ‘Ideal Technologies, Ideal Women’, 724; Brandtzaeg and Følstad, ‘Chatbots’, 43; Jacobs, ‘Digital Loneliness—Changes of Social Recognition through AI Companions’, 2; Surkalim et al., ‘The Prevalence of Loneliness across 113 Countries’, 7. [↑](#footnote-ref-83)
83. Turkle, *The Second Self*, 57. [↑](#footnote-ref-84)
84. Bartneck et al., *Human-Robot Interaction*, 119. [↑](#footnote-ref-85)
85. Bagheri et al., ‘A Reinforcement Learning Based Cognitive Empathy Framework for Social Robots’, 1079; Leite et al., ‘Empathic Robots for Long-Term Interaction’, 329; Malle and Thapa, ‘What Kind of Mind Do I Want in My Robot?’, 196; Park and Whang, ‘Empathy in Human–Robot Interaction’, 16; Quick, ‘Empathizing and Sympathizing With Robots’. [↑](#footnote-ref-86)
86. James, Watson, and MacDonald, ‘Artificial Empathy in Social Robots’, 632; Pepito et al., ‘Intelligent Humanoid Robots Expressing Artificial Humanlike Empathy in Nursing Situations’, 1; Vallverdú and Casacuberta, ‘Ethical and Technical Aspects of Emotions to Create Empathy in Medical Machines’, 341. [↑](#footnote-ref-87)
87. Bartneck et al., *Human-Robot Interaction*, 46. [↑](#footnote-ref-88)
88. Coplan, ‘Understanding Empathy’, 5; Cuff et al., ‘Empathy’, 144. [↑](#footnote-ref-89)
89. Cuff et al., ‘Empathy’, 147; Schertz, ‘Empathy as Intersubjectivity’, 165. [↑](#footnote-ref-90)
90. Shamay-Tsoory, ‘Empathic Processing’, 216. [↑](#footnote-ref-91)
91. Angell, ‘Titchener at Leipzig’, 195–96. [↑](#footnote-ref-92)
92. Agosta, *Empathy in the Context of Philosophy*, 6; Stueber, ‘Empathy’, sec. 1. [↑](#footnote-ref-93)
93. Montag, Gallinat, and Heinz, ‘Theodor Lipps and the Concept of Empathy’, 1261; Stueber, *Rediscovering Empathy*, 6. [↑](#footnote-ref-94)
94. Coplan and Goldie, ‘Introduction’, XII; Stueber, *Rediscovering Empathy*, 7. [↑](#footnote-ref-95)
95. Zahavi, ‘Empathy and Other-Directed Intentionality’, 130. [↑](#footnote-ref-96)
96. Stueber, *Rediscovering Empathy*, 7–8. [↑](#footnote-ref-97)
97. Coplan and Goldie, ‘Introduction’, XII. [↑](#footnote-ref-98)
98. Stueber, *Rediscovering Empathy*, 9. [↑](#footnote-ref-99)
99. Coplan and Goldie, ‘Introduction’, XII; Montag, Gallinat, and Heinz, ‘Theodor Lipps and the Concept of Empathy’, 1261. [↑](#footnote-ref-100)
100. Hume, *A Treatise of Human Nature*, 236. [↑](#footnote-ref-101)
101. Coplan and Goldie, ‘Introduction’, X; Schertz, ‘Empathy as Intersubjectivity’, 167. [↑](#footnote-ref-102)
102. Hume, *A Treatise of Human Nature*, 7. [↑](#footnote-ref-103)
103. Hume, 206. [↑](#footnote-ref-104)
104. Schertz, ‘Empathy as Intersubjectivity’, 168. [↑](#footnote-ref-105)
105. Stueber, *Rediscovering Empathy*, 31. [↑](#footnote-ref-106)
106. Schertz, ‘Empathy as Intersubjectivity’, 169; Coplan and Goldie, ‘Introduction’, XI. [↑](#footnote-ref-107)
107. Schertz, ‘Empathy as Intersubjectivity’, 170. [↑](#footnote-ref-108)
108. Darwall, ‘Empathy, Sympathy, Care’, 273; Eisenberg and Eggum, ‘Empathic Responding’, 71; Cuff et al., ‘Empathy’, 145. [↑](#footnote-ref-109)
109. Burns, ‘Empathy, Simulation, and Neuroscience’, 214; Hein and Singer, ‘I Feel How You Feel but Not Always’, 154. [↑](#footnote-ref-110)
110. Coplan and Goldie, ‘Introduction’, 10. [↑](#footnote-ref-111)
111. Hein and Singer, ‘I Feel How You Feel but Not Always’, 157. [↑](#footnote-ref-112)
112. Debes, ‘From Einfühlung to Empathy’, 290; Wispé, ‘History of the Concept of Empathy’, 20. [↑](#footnote-ref-113)
113. Agosta, *Empathy in the Context of Philosophy*, 5. [↑](#footnote-ref-114)
114. Agosta, 113. [↑](#footnote-ref-115)
115. Stein, *On the Problem of Empathy*, 11; Coplan and Goldie, ‘Introduction’, XIII. [↑](#footnote-ref-116)
116. Zahavi, ‘Empathy and Other-Directed Intentionality’, 133. [↑](#footnote-ref-117)
117. Zahavi, 131. [↑](#footnote-ref-118)
118. Zahavi, 132. [↑](#footnote-ref-119)
119. Stueber, ‘Empathy’, sec. 2. [↑](#footnote-ref-120)
120. Debes, ‘From Einfühlung to Empathy’, 318–19; Stueber, *Rediscovering Empathy*, 17; Wispé, ‘History of the Concept of Empathy’, 23–24. [↑](#footnote-ref-121)
121. Stueber, *Rediscovering Empathy*, 2. [↑](#footnote-ref-122)
122. Stueber, 20. [↑](#footnote-ref-123)
123. Stueber, 111. [↑](#footnote-ref-124)
124. Goldman, ‘Interpretation Psychologized’, 173; Pfeifer and Dapretto, ‘“Mirror, Mirror, in My Mind”’, 186. [↑](#footnote-ref-125)
125. Goldman, ‘Two Routes to Empathy’, 33; Oberman and Ramachandran, ‘Reflections on the Mirror Neuron System’, 40. [↑](#footnote-ref-126)
126. Iacoboni, ‘Imitation, Empathy, and Mirror Neurons’, 659. [↑](#footnote-ref-127)
127. Iacoboni, 657; Decety and Jackson, ‘The Functional Architecture of Human Empathy’, 80; van Baaren et al., ‘Being Imitated’, 31. [↑](#footnote-ref-128)
128. Cook et al., ‘Mirror Neurons’, 180; Hickok, ‘Eight Problems for the Mirror Neuron Theory of Action Understanding in Monkeys and Humans’, 1230; Heyes and Catmur, ‘What Happened to Mirror Neurons?’, 161. [↑](#footnote-ref-129)
129. Decety and Meyer, ‘From Emotion Resonance to Empathic Understanding’, 1058–59. [↑](#footnote-ref-130)
130. Iacoboni, ‘Within Each Other’, 49. [↑](#footnote-ref-131)
131. Hickok, *The Myth of Mirror Neurons*, 111–12. [↑](#footnote-ref-132)
132. Cook et al., ‘Mirror Neurons’, 181. [↑](#footnote-ref-133)
133. Hickok, ‘Eight Problems for the Mirror Neuron Theory of Action Understanding in Monkeys and Humans’, 1236. [↑](#footnote-ref-134)
134. Cook et al., ‘Mirror Neurons’, 184. [↑](#footnote-ref-135)
135. Heyes and Catmur, ‘What Happened to Mirror Neurons?’, 161. [↑](#footnote-ref-136)
136. Hatfield, Rapson, and Le, ‘Emotional Contagion and Empathy’, 19; van Baaren et al., ‘Being Imitated’, 32. [↑](#footnote-ref-137)
137. Carter, Harri, and Porges, ‘Neural and Evolutionary Perspectives on Empathy’, 170; Prochazkova and Kret, ‘Connecting Minds and Sharing Emotions through Mimicry’, 100. [↑](#footnote-ref-138)
138. van Baaren et al., ‘Being Imitated’, 34–35; Decety and Meyer, ‘From Emotion Resonance to Empathic Understanding’, 1054. [↑](#footnote-ref-139)
139. de Waal and Preston, ‘Mammalian Empathy’, 503; Iacoboni, ‘Imitation, Empathy, and Mirror Neurons’, 666–67. [↑](#footnote-ref-140)
140. Chong and Mattingley, ‘Automatic and Controlled Processing within the Mirror Neuron System’, 216; Goldman, ‘Two Routes to Empathy’, 38. [↑](#footnote-ref-141)
141. Plutchik, ‘Evolutionary Bases of Empathy’, 44. [↑](#footnote-ref-142)
142. de Waal, ‘Empathy in Primates and Other Mammals’, 100. [↑](#footnote-ref-143)
143. de Waal and Preston, ‘Mammalian Empathy’, 499. [↑](#footnote-ref-144)
144. de Waal and Preston, 500. [↑](#footnote-ref-145)
145. Carter, Harri, and Porges, ‘Neural and Evolutionary Perspectives on Empathy’, 173; de Waal and Preston, ‘Mammalian Empathy’, 507. [↑](#footnote-ref-146)
146. de Waal and Preston, ‘Mammalian Empathy’, 502. [↑](#footnote-ref-147)
147. de Waal and Preston, 501. [↑](#footnote-ref-148)
148. de Waal and Preston, 502. [↑](#footnote-ref-149)
149. Warneken and Tomasello, ‘Extrinsic Rewards Undermine Altruistic Tendencies in 20-Month-Olds’, 1787. [↑](#footnote-ref-150)
150. Ickes, ‘Empathic Accuracy’, 57. [↑](#footnote-ref-151)
151. Debes, ‘Which Empathy?’, 234; Nickerson, Butler, and Carlin, ‘Empathy and Knowledge Projection’, 51; Stueber, *Rediscovering Empathy*, 136. [↑](#footnote-ref-152)
152. Burns, ‘Empathy, Simulation, and Neuroscience’, 214; Stueber, *Rediscovering Empathy*, 196. [↑](#footnote-ref-153)
153. Decety and Meyer, ‘From Emotion Resonance to Empathic Understanding’, 1056; Heyes, ‘Empathy Is Not in Our Genes’, 500. [↑](#footnote-ref-154)
154. Decety and Meltzoff, ‘Empathy, Imitation, and the Social Brain’, 59. [↑](#footnote-ref-155)
155. Decety and Jackson, ‘The Functional Architecture of Human Empathy’, 75; Decety and Meltzoff, ‘Empathy, Imitation, and the Social Brain’, 62; Siegler, DeLoache, and Eisenberg, *How Children Develop*, 270. [↑](#footnote-ref-156)
156. Decety and Meyer, ‘From Emotion Resonance to Empathic Understanding’, 1057; Zahavi and Rochat, ‘Empathy≠sharing’, 547. [↑](#footnote-ref-157)
157. Carpenter et al., ‘Social Cognition, Joint Attention, and Communicative Competence from 9 to 15 Months of Age’, 1; Siegler, DeLoache, and Eisenberg, *How Children Develop*, 159. [↑](#footnote-ref-158)
158. Siegler, DeLoache, and Eisenberg, *How Children Develop*, 269; Warneken and Tomasello, ‘Altruistic Helping in Human Infants and Young Chimpanzees’, 1301. [↑](#footnote-ref-159)
159. Bloom and German, ‘Two Reasons to Abandon the False Belief Task as a Test of Theory of Mind’, B27; Helming, Strickland, and Jacob, ‘Making Sense of Early False-Belief Understanding’, 169; Siegler, DeLoache, and Eisenberg, *How Children Develop*, 271. [↑](#footnote-ref-160)
160. Schidelko et al., ‘Why Do Children Who Solve False Belief Tasks Begin to Find True Belief Control Tasks Difficult?’, 1–2. [↑](#footnote-ref-161)
161. Bloom and German, ‘Two Reasons to Abandon the False Belief Task as a Test of Theory of Mind’, B30. [↑](#footnote-ref-162)
162. Tremblay et al., ‘Functional Connectivity Patterns of Trait Empathy Are Associated with Age’, 105859. [↑](#footnote-ref-163)
163. Gallagher, ‘Inference or Interaction’, 164; Gallagher, ‘Neurons, Neonates and Narrative’, 173–74. [↑](#footnote-ref-164)
164. Gallagher, ‘The Practice of Mind. Theory, Simulation or Primary Interaction?’, 90–91. [↑](#footnote-ref-165)
165. Gallagher, ‘Neurons, Neonates and Narrative’, 174; Gallagher, ‘The Practice of Mind. Theory, Simulation or Primary Interaction?’, 99. [↑](#footnote-ref-166)
166. Gallagher, ‘Neurons, Neonates and Narrative’, 174. [↑](#footnote-ref-167)
167. Gallagher, ‘Inference or Interaction’, 165; Gallagher, ‘Neurons, Neonates and Narrative’, 175; Gallagher, ‘The Practice of Mind. Theory, Simulation or Primary Interaction?’, 86. [↑](#footnote-ref-168)
168. Gallagher, ‘Neurons, Neonates and Narrative’, 181. [↑](#footnote-ref-169)
169. Gallagher, 182; Gallagher, ‘The Practice of Mind. Theory, Simulation or Primary Interaction?’, 88–89. [↑](#footnote-ref-170)
170. Gallagher, ‘Inference or Interaction’, 165; Siegler, DeLoache, and Eisenberg, *How Children Develop*, 268–69. [↑](#footnote-ref-171)
171. Gallagher, ‘Neurons, Neonates and Narrative’, 182. [↑](#footnote-ref-172)
172. Gallagher, 183. [↑](#footnote-ref-173)
173. Gallagher, ‘Inference or Interaction’, 166. [↑](#footnote-ref-174)
174. Gallagher, ‘Neurons, Neonates and Narrative’, 186. [↑](#footnote-ref-175)
175. Gallagher, 186; Gallagher, ‘The Practice of Mind. Theory, Simulation or Primary Interaction?’, 96. [↑](#footnote-ref-176)
176. Porter and Samovar, ‘Cultural Influences on Emotional Expression’, 457. [↑](#footnote-ref-177)
177. Hickok, *The Myth of Mirror Neurons*, 241. [↑](#footnote-ref-178)
178. Adami, ‘A Brief History of Artificial Intelligence Research’, 133; McCorduck, *Machines Who Think*, 4; Crevier, *AI*, 2. [↑](#footnote-ref-179)
179. Ekmekci and Arda, ‘History of Artificial Intelligence’, 1–2; Buchanan, ‘A (Very) Brief History of Artificial Intelligence’, 53. [↑](#footnote-ref-180)
180. Lungarella et al., ‘AI in the 21st Century – With Historical Reflections’, 1; Ekmekci and Arda, ‘History of Artificial Intelligence’, 3. [↑](#footnote-ref-181)
181. Adami, ‘A Brief History of Artificial Intelligence Research’, 133; Steels, ‘Fifty Years of AI’, 23. [↑](#footnote-ref-182)
182. Haenlein and Kaplan, ‘A Brief History of Artificial Intelligence’, 6; Lee, *Artificial Intelligence in Daily Life*, 25–26. [↑](#footnote-ref-183)
183. Haikonen, *The Cognitive Approach to Conscious Machines*, 15–16. [↑](#footnote-ref-184)
184. Rojas, ‘Konrad Zuse’s Legacy’, 5. [↑](#footnote-ref-185)
185. Rojas, 5–6. [↑](#footnote-ref-186)
186. Haenlein and Kaplan, ‘A Brief History of Artificial Intelligence’, 6. [↑](#footnote-ref-187)
187. Ekmekci and Arda, ‘History of Artificial Intelligence’, 5; Lee, *Artificial Intelligence in Daily Life*, 22; Franklin, ‘History, Motivations, and Core Themes’, 16. [↑](#footnote-ref-188)
188. Ekmekci and Arda, ‘History of Artificial Intelligence’, 5; McCorduck, *Machines Who Think*, 56. [↑](#footnote-ref-189)
189. Williams, ‘The Origins, Uses, and Fate of the EDVAC’, 22. [↑](#footnote-ref-190)
190. Williams, 23. [↑](#footnote-ref-191)
191. McCorduck, *Machines Who Think*, 78; Rojas and Hashagen, ‘“Nothing New Since von Neumann”’, 195. [↑](#footnote-ref-192)
192. Haikonen, *The Cognitive Approach to Conscious Machines*, 17; Lee, *Artificial Intelligence in Daily Life*, 43. [↑](#footnote-ref-193)
193. Buchanan, ‘A (Very) Brief History of Artificial Intelligence’, 54; McCorduck, *Machines Who Think*, 78. [↑](#footnote-ref-194)
194. O’Regan, *A Brief History of Computing*, 27–28. [↑](#footnote-ref-195)
195. Adami, ‘A Brief History of Artificial Intelligence Research’, 133; Russell and Norvig, *Artificial Intelligence*, 15. [↑](#footnote-ref-196)
196. Berkeley, *Giant Brains, or Machines That Think*, 1. [↑](#footnote-ref-197)
197. Berkeley, 5. [↑](#footnote-ref-198)
198. Franklin, ‘History, Motivations, and Core Themes’, 17; Turing, ‘Computing Machinery and Intelligence.’, 434. [↑](#footnote-ref-199)
199. Ekmekci and Arda, ‘History of Artificial Intelligence’, 6; Shannon, ‘Programming a Computer for Playing Chess’, 256. [↑](#footnote-ref-200)
200. Franklin, ‘History, Motivations, and Core Themes’, 19; Russell and Norvig, *Artificial Intelligence*, 16. [↑](#footnote-ref-201)
201. Nilsson, *The Quest for Artificial Intelligence*, 49–50. [↑](#footnote-ref-202)
202. Nilsson, 49. [↑](#footnote-ref-203)
203. Nilsson, 52. [↑](#footnote-ref-204)
204. Nilsson, 50–51; Pitts, ‘Comments on Session on Learning Machines’, 110. [↑](#footnote-ref-205)
205. McCorduck et al., ‘History of Artificial Intelligence’, 953; Moor, ‘The Dartmouth College Artificial Intelligence Conference’, 87. [↑](#footnote-ref-206)
206. Ekmekci and Arda, ‘History of Artificial Intelligence’, 7; McCorduck et al., ‘History of Artificial Intelligence’, 953. [↑](#footnote-ref-207)
207. Lee, *Artificial Intelligence in Daily Life*, 23; Nilsson, *The Quest for Artificial Intelligence*, 53. [↑](#footnote-ref-208)
208. Gugerty, ‘Newell and Simon’s Logic Theorist’, 880; Nilsson, *The Quest for Artificial Intelligence*, 54. [↑](#footnote-ref-209)
209. Flasiński, ‘History of Artificial Intelligence’, 4; Nilsson, *The Quest for Artificial Intelligence*, 56. [↑](#footnote-ref-210)
210. Davies, ‘Mechanization of Thought Processes’, 225; Nilsson, *The Quest for Artificial Intelligence*, 57. [↑](#footnote-ref-211)
211. Lungarella et al., ‘AI in the 21st Century – With Historical Reflections’, 2; Steels, ‘Fifty Years of AI’, 20.. [↑](#footnote-ref-212)
212. Franklin, ‘History, Motivations, and Core Themes’, 24–25; Steels, ‘Fifty Years of AI’, 22. [↑](#footnote-ref-213)
213. Boden, ‘GOFAI’, 90. [↑](#footnote-ref-214)
214. Frankish and Ramsey, *The Cambridge Handbook of Artificial Intelligence*, 339; Flasiński, ‘History of Artificial Intelligence’, 5; Franklin, ‘History, Motivations, and Core Themes’, 20. [↑](#footnote-ref-215)
215. Davies, ‘Mechanization of Thought Processes’, 225; McCorduck, *Machines Who Think*, 254; Russell and Norvig, *Artificial Intelligence*, 19. [↑](#footnote-ref-216)
216. Dreyfus, *What Computers Can’t Do*, xxiv; Lee, *Artificial Intelligence in Daily Life*, 23; Nilsson, *The Quest for Artificial Intelligence*, 88. [↑](#footnote-ref-217)
217. McCorduck, *Machines Who Think*, 247; Nilsson, *The Quest for Artificial Intelligence*, 88–89. [↑](#footnote-ref-218)
218. Davies, ‘Mechanization of Thought Processes’, 225; Nilsson, *The Quest for Artificial Intelligence*, 64; Sejnowski, *The Deep Learning Revolution*, 2018, 39. [↑](#footnote-ref-219)
219. Lefkowitz, ‘Professor’s Perceptron Paved the Way for AI – 60 Years Too Soon’; Sun, ‘Connectionism and Neural Networks’, 110. [↑](#footnote-ref-220)
220. Sun, ‘Connectionism and Neural Networks’, 109. [↑](#footnote-ref-221)
221. Ekmekci and Arda, ‘History of Artificial Intelligence’, 10; Flasiński, ‘History of Artificial Intelligence’, 10. [↑](#footnote-ref-222)
222. Adami, ‘A Brief History of Artificial Intelligence Research’, 133; Franklin, ‘History, Motivations, and Core Themes’, 31; Sun, ‘Connectionism and Neural Networks’, 119. [↑](#footnote-ref-223)
223. Lee, *Artificial Intelligence in Daily Life*, 22. [↑](#footnote-ref-224)
224. Crevier, *AI*, 65; Lee, *Artificial Intelligence in Daily Life*, 24; McCorduck, *Machines Who Think*, 131. [↑](#footnote-ref-225)
225. Buchanan, ‘A (Very) Brief History of Artificial Intelligence’, 59; Ekmekci and Arda, ‘History of Artificial Intelligence’, 10; McCorduck, *Machines Who Think*, 131. [↑](#footnote-ref-226)
226. Kaynak, ‘The Golden Age of Artificial Intelligence’, 2; Russell and Norvig, *Artificial Intelligence*, 19. [↑](#footnote-ref-227)
227. Buchanan, ‘A (Very) Brief History of Artificial Intelligence’, 56. [↑](#footnote-ref-228)
228. McCorduck, *Machines Who Think*, 261. [↑](#footnote-ref-229)
229. Moravec, *Robot*, 15–16; Bhaumik, *From AI to Robotics*, 12. [↑](#footnote-ref-230)
230. Hudson, *The Robot Revolution*, 22; Moravec, *Mind Children*, 10–11. [↑](#footnote-ref-231)
231. Husbands, ‘Robotics’, 273; Nilsson, *The Quest for Artificial Intelligence*, 164. [↑](#footnote-ref-232)
232. Weizenbaum, ‘ELIZA—A Computer Program For the Study of Natural Language Communication Between Man And Machine’, 36; Weizenbaum, *Computer Power and Human Reason*, 6. [↑](#footnote-ref-233)
233. Crevier, *AI*, 134; Weizenbaum, ‘ELIZA—A Computer Program For the Study of Natural Language Communication Between Man And Machine’, 42. [↑](#footnote-ref-234)
234. Weizenbaum, ‘ELIZA—A Computer Program For the Study of Natural Language Communication Between Man And Machine’, 43. [↑](#footnote-ref-235)
235. McCorduck, *Machines Who Think*, 296; Weizenbaum, ‘ELIZA—A Computer Program For the Study of Natural Language Communication Between Man And Machine’, 42–43. [↑](#footnote-ref-236)
236. Crevier, *AI*, 133; Wooldridge, *A Brief History of Artificial Intelligence*, 25. [↑](#footnote-ref-237)
237. Wooldridge, *A Brief History of Artificial Intelligence*, 35. [↑](#footnote-ref-238)
238. Dreyfus, *What Computers Can’t Do*, xxix; Russell and Norvig, *Artificial Intelligence*, 21. [↑](#footnote-ref-239)
239. Kaynak, ‘The Golden Age of Artificial Intelligence’, 3. [↑](#footnote-ref-240)
240. Minsky, *Computation*, 2. [↑](#footnote-ref-241)
241. Flasiński, ‘History of Artificial Intelligence’, 10; Olazaran, ‘A Sociological Study of the Official History of the Perceptrons Controversy’, 629; Sejnowski, *The Deep Learning Revolution*, 2018, 47. [↑](#footnote-ref-242)
242. Olazaran, ‘A Sociological Study of the Official History of the Perceptrons Controversy’, 625–26; Haikonen, *Consciousness and Robot Sentience*, 85. [↑](#footnote-ref-243)
243. O’Connor, ‘Undercover Algorithm’, 10; Lee, *Artificial Intelligence in Daily Life*, 24. [↑](#footnote-ref-244)
244. Dreyfus, *What Computers Can’t Do*, 200; Crevier, *AI*, 124–25; Wooldridge, *A Brief History of Artificial Intelligence*, 216. [↑](#footnote-ref-245)
245. Lee, *Artificial Intelligence in Daily Life*, 24; Lighthill, ‘Artificial Intelligence: A General Survey’; Russell and Norvig, *Artificial Intelligence*, 22. [↑](#footnote-ref-246)
246. Wooldridge, *A Brief History of Artificial Intelligence*, 60. [↑](#footnote-ref-247)
247. Crevier, *AI*, 116; Wooldridge, *A Brief History of Artificial Intelligence*, 62. [↑](#footnote-ref-248)
248. Crevier, *AI*, 117. [↑](#footnote-ref-249)
249. Franklin, ‘History, Motivations, and Core Themes’, 20. [↑](#footnote-ref-250)
250. Flasiński, ‘History of Artificial Intelligence’, 10; Kohonen, ‘Correlation Matrix Memories’, 353. [↑](#footnote-ref-251)
251. Rosenfeld, ‘Teuvo Kohonen’, 154. [↑](#footnote-ref-252)
252. Hudson, *The Robot Revolution*, 23; Lee, *Artificial Intelligence in Daily Life*, 25. [↑](#footnote-ref-253)
253. Franklin, ‘History, Motivations, and Core Themes’, 20. [↑](#footnote-ref-254)
254. von der Malsburg, ‘Self-Organization of Orientation Sensitive Cells in the Striate Cortex’, 85. [↑](#footnote-ref-255)
255. von der Malsburg, 85. [↑](#footnote-ref-256)
256. Flasiński, ‘History of Artificial Intelligence’, 10; Fukushima, ‘Cognitron’, 122–23. [↑](#footnote-ref-257)
257. Ekmekci and Arda, ‘History of Artificial Intelligence’, 13; Lee, *Artificial Intelligence in Daily Life*, 25. [↑](#footnote-ref-258)
258. Lee, *Artificial Intelligence in Daily Life*, 25. [↑](#footnote-ref-259)
259. Sejnowski, *The Deep Learning Revolution*, 2018, 79. [↑](#footnote-ref-260)
260. Franklin, ‘History, Motivations, and Core Themes’, 21; Russell and Norvig, *Artificial Intelligence*, 24. [↑](#footnote-ref-261)
261. Franklin, ‘History, Motivations, and Core Themes’, 21; Wooldridge, *A Brief History of Artificial Intelligence*, 117–18. [↑](#footnote-ref-262)
262. Crevier, *AI*, 199. [↑](#footnote-ref-263)
263. Kaynak, ‘The Golden Age of Artificial Intelligence’, 3; Lee, *Artificial Intelligence in Daily Life*, 26. [↑](#footnote-ref-264)
264. Russell and Norvig, *Artificial Intelligence*, 694–95. [↑](#footnote-ref-265)
265. Haikonen, *Consciousness and Robot Sentience*, 90. [↑](#footnote-ref-266)
266. Hastie, Tibshirani, and Friedman, ‘Unsupervised Learning’, 485; Russell and Norvig, *Artificial Intelligence*, 757. [↑](#footnote-ref-267)
267. Dike et al., ‘Unsupervised Learning Based On Artificial Neural Network’, 324; Watson, ‘On the Philosophy of Unsupervised Learning’, 3. [↑](#footnote-ref-268)
268. Russell and Norvig, *Artificial Intelligence*, 830. [↑](#footnote-ref-269)
269. Hastie, Tibshirani, and Friedman, ‘Unsupervised Learning’, 485. [↑](#footnote-ref-270)
270. Russell and Norvig, *Artificial Intelligence*, 985. [↑](#footnote-ref-271)
271. Russell and Norvig, 830. [↑](#footnote-ref-272)
272. Lee, *Artificial Intelligence in Daily Life*, 26; McCorduck, *Machines Who Think*, 532. [↑](#footnote-ref-273)
273. Crevier, *AI*, 210. [↑](#footnote-ref-274)
274. Crevier, 197; Wooldridge, *A Brief History of Artificial Intelligence*, 69. [↑](#footnote-ref-275)
275. Crevier, *AI*, 204; Lee, *Artificial Intelligence in Daily Life*, 26. [↑](#footnote-ref-276)
276. Crevier, *AI*, 211; Lee, *Artificial Intelligence in Daily Life*, 26. [↑](#footnote-ref-277)
277. Lee, *Artificial Intelligence in Daily Life*, 27. [↑](#footnote-ref-278)
278. Baldwin, *The Globotics Upheaval*, 104. [↑](#footnote-ref-279)
279. Beer, ‘Dynamical Systems and Embedded Cognition’, 128; Lee, *Artificial Intelligence in Daily Life*, 27. [↑](#footnote-ref-280)
280. Husbands, ‘Robotics’, 272; McCorduck, *Machines Who Think*, 442. [↑](#footnote-ref-281)
281. Steels, ‘Fifty Years of AI’, 23. [↑](#footnote-ref-282)
282. Arkoudas and Bringsjord, ‘Philosophical Foundations’, 55. [↑](#footnote-ref-283)
283. Wooldridge, *A Brief History of Artificial Intelligence*, 93. [↑](#footnote-ref-284)
284. Brooks, ‘Elephants Don’t Play Chess’, 3. [↑](#footnote-ref-285)
285. Brooks, 4. [↑](#footnote-ref-286)
286. Brooks, 4–5; Dreyfus, *What Computers Can’t Do*, 61. [↑](#footnote-ref-287)
287. Brooks, ‘Elephants Don’t Play Chess’, 5. [↑](#footnote-ref-288)
288. Brooks, 14. [↑](#footnote-ref-289)
289. Alonso, ‘Actions and Agents’, 235. [↑](#footnote-ref-290)
290. Ekmekci and Arda, ‘History of Artificial Intelligence’, 13; Lee, *Artificial Intelligence in Daily Life*, 27. [↑](#footnote-ref-291)
291. Brooks et al., ‘The Cog Project’, 52; McCorduck, *Machines Who Think*, 463. [↑](#footnote-ref-292)
292. MIT, ‘People Overview Cynthia Breazeal’. [↑](#footnote-ref-293)
293. Husbands, ‘Robotics’, 278. [↑](#footnote-ref-294)
294. Franklin, ‘History, Motivations, and Core Themes’, 23; Haenlein and Kaplan, ‘A Brief History of Artificial Intelligence’, 8; Lungarella et al., ‘AI in the 21st Century – With Historical Reflections’, 3. [↑](#footnote-ref-295)
295. Lee, *How to Grow a Robot*, 29. [↑](#footnote-ref-296)
296. Husbands, ‘Robotics’, 278–79. [↑](#footnote-ref-297)
297. Cangelosi and Schlesinger, *Developmental Robotics*, 5. [↑](#footnote-ref-298)
298. Adami, ‘A Brief History of Artificial Intelligence Research’, 132; Cangelosi and Schlesinger, ‘From Babies to Robots’, 184; Lee, *How to Grow a Robot*, 232. [↑](#footnote-ref-299)
299. Clark, *Being There*, 113; Thompson, ‘Sensorimotor Subjectivity and the Enactive Approach to Experience’, 13; Ziemke, ‘The Body of Knowledge’, 9. [↑](#footnote-ref-300)
300. Lungarella et al., ‘AI in the 21st Century – With Historical Reflections’, 3; Vernon and Furlong, ‘Philosophical Foundations of AI’, 60. [↑](#footnote-ref-301)
301. Bhaumik, *From AI to Robotics*, 34. [↑](#footnote-ref-302)
302. Law et al., ‘Infants and iCubs’, 273. [↑](#footnote-ref-303)
303. Lungarella et al., ‘AI in the 21st Century – With Historical Reflections’, 5; Hoffmann and Pfeifer, ‘Robots as Powerful Allies for the Study of Embodied Cognition from the Bottom Up’, 850. [↑](#footnote-ref-304)
304. Haenlein and Kaplan, ‘A Brief History of Artificial Intelligence’, 5. [↑](#footnote-ref-305)
305. Boyd and Crawford, ‘Critical Questions for Big Data’, 663–64; Leonelli, ‘Scientific Research and Big Data’. [↑](#footnote-ref-306)
306. Sejnowski, *The Deep Learning Revolution*, 2018, 25; Wooldridge, *A Brief History of Artificial Intelligence*, 139. [↑](#footnote-ref-307)
307. Wooldridge, *A Brief History of Artificial Intelligence*, 97–98. [↑](#footnote-ref-308)
308. Franklin, ‘History, Motivations, and Core Themes’, 23. [↑](#footnote-ref-309)
309. Hodson, ‘The First Family Robot’, 21. [↑](#footnote-ref-310)
310. Wooldridge, *A Brief History of Artificial Intelligence*, 123–24. [↑](#footnote-ref-311)
311. Wooldridge, 127. [↑](#footnote-ref-312)
312. Kasneci et al., ‘ChatGPT for Good?’, 1. [↑](#footnote-ref-313)
313. Ribas, ‘Building the New Bing’. [↑](#footnote-ref-314)
314. OpenAI, ‘Sora’. [↑](#footnote-ref-315)
315. Metta et al., ‘The iCub Humanoid Robot’, 1133. [↑](#footnote-ref-316)
316. Istituto Italiano di Tecnologia, ‘iCub History’; Sandini, Metta, and Vernon, ‘RobotCub’, 13. [↑](#footnote-ref-317)
317. Metta et al., ‘iCub’, 1; Parmiggiani et al., ‘The Design of the iCub Humanoid Robot’, 3. [↑](#footnote-ref-318)
318. Metta et al., ‘iCub’, 1–2. [↑](#footnote-ref-319)
319. Metta et al., 2–3. [↑](#footnote-ref-320)
320. Parmiggiani et al., ‘The Design of the iCub Humanoid Robot’, 15. [↑](#footnote-ref-321)
321. Metta et al., ‘The iCub Humanoid Robot’, 1127. [↑](#footnote-ref-322)
322. Sandini, Metta, and Vernon, ‘The iCub Cognitive Humanoid Robot’, 361. [↑](#footnote-ref-323)
323. Metta et al., ‘iCub’, 3–4. [↑](#footnote-ref-324)
324. Parmiggiani et al., ‘The Design of the iCub Humanoid Robot’, 20. [↑](#footnote-ref-325)
325. Natale et al., ‘The iCub Software Architecture’, 2. [↑](#footnote-ref-326)
326. Sandini, Metta, and Vernon, ‘The iCub Cognitive Humanoid Robot’, 363. [↑](#footnote-ref-327)
327. Natale et al., ‘The iCub Software Architecture’, 4; ‘The Orocos Project’. [↑](#footnote-ref-328)
328. Natale et al., ‘The iCub Software Architecture’, 2. [↑](#footnote-ref-329)
329. Metta et al., ‘The iCub Humanoid Robot’, 1130. [↑](#footnote-ref-330)
330. Metta et al., 1130. [↑](#footnote-ref-331)
331. Metta et al., ‘iCub’, 5. [↑](#footnote-ref-332)
332. Natale et al., ‘The iCub Software Architecture’, 16. [↑](#footnote-ref-333)
333. Fischer et al., ‘iCub-HRI’, 3–4. [↑](#footnote-ref-334)
334. Vernon, Metta, and Sandini, ‘The iCub Cognitive Architecture’, 124. [↑](#footnote-ref-335)
335. Law et al., ‘Infants and iCubs’, 273. [↑](#footnote-ref-336)
336. Vernon, Metta, and Sandini, ‘The iCub Cognitive Architecture’, 124. [↑](#footnote-ref-337)
337. Sandini, Metta, and Vernon, ‘The iCub Cognitive Humanoid Robot’, 365–66. [↑](#footnote-ref-338)
338. Sandini, Metta, and Vernon, 364. [↑](#footnote-ref-339)
339. Vernon, Metta, and Sandini, ‘The iCub Cognitive Architecture’, 124. [↑](#footnote-ref-340)
340. Shaw, Law, and Lee, ‘Representations of Body Schemas for Infant Robot Development’, 127. [↑](#footnote-ref-341)
341. Sandini, Metta, and Vernon, ‘The iCub Cognitive Humanoid Robot’, 365. [↑](#footnote-ref-342)
342. Metta et al., ‘The iCub Humanoid Robot’, 1131. [↑](#footnote-ref-343)
343. Gibson, *The Ecological Approach to Visual Perception*, 127. [↑](#footnote-ref-344)
344. Gibson, 128. [↑](#footnote-ref-345)
345. Metta et al., ‘The iCub Humanoid Robot’, 1131–32. [↑](#footnote-ref-346)
346. Mar et al., ‘Self-Supervised Learning of Grasp Dependent Tool Affordances on the iCub Humanoid Robot’. [↑](#footnote-ref-347)
347. Marocco et al., ‘Grounding Action Words in the Sensorimotor Interaction with the World’, 11. [↑](#footnote-ref-348)
348. Tikhanoff et al., ‘An Open-Source Simulator for Cognitive Robotics Research’. [↑](#footnote-ref-349)
349. Cangelosi et al., ‘The iTalk Project’, 12; Tikhanoff, Cangelosi, and Metta, ‘Integration of Speech and Action in Humanoid Robots’, 27. [↑](#footnote-ref-350)
350. Cangelosi and Schlesinger, ‘From Babies to Robots’, 2. [↑](#footnote-ref-351)
351. Morse et al., ‘Epigenetic Robotics Architecture (ERA)’, 335. [↑](#footnote-ref-352)
352. Churamani et al., ‘iCub’, 1. [↑](#footnote-ref-353)
353. Tanevska et al., ‘A Cognitive Architecture for Socially Adaptable Robots’, 200. [↑](#footnote-ref-354)
354. Tanevska et al., 199. [↑](#footnote-ref-355)
355. Tanevska et al., ‘Towards an Affective Cognitive Architecture for Human-Robot Interaction for the iCub Robot’, 4. [↑](#footnote-ref-356)
356. Di Nuovo et al., ‘The iCub Learns Numbers’, 693. [↑](#footnote-ref-357)
357. Di Nuovo et al., 698. [↑](#footnote-ref-358)
358. Harnad, ‘Other Bodies, Other Minds’, 44. [↑](#footnote-ref-359)
359. Harnad, 44. [↑](#footnote-ref-360)
360. Harnad, 50–51. [↑](#footnote-ref-361)
361. Harnad, 51. [↑](#footnote-ref-362)
362. Harnad, 46. [↑](#footnote-ref-363)
363. Ekman, ‘Body Position, Facial Expression, and Verbal Behavior during Interviews’, 300; Ekman and Friesen, ‘Head and Body Cues in the Judgment of Emotion’, 718. [↑](#footnote-ref-364)
364. Ekman, ‘Darwin’s Contributions to Our Understanding of Emotional Expressions’, 3449. [↑](#footnote-ref-365)
365. Ekman, ‘An Argument for Basic Emotions’, 170. [↑](#footnote-ref-366)
366. Ekman, 175. [↑](#footnote-ref-367)
367. Ekman, 172. [↑](#footnote-ref-368)
368. Ekman, ‘Universal Facial Expressions of Emotion’, 152–53. [↑](#footnote-ref-369)
369. Ekman, ‘An Argument for Basic Emotions’, 173. [↑](#footnote-ref-370)
370. Ekman, ‘Are There Basic Emotions?’, 552. [↑](#footnote-ref-371)
371. Ekman, ‘An Argument for Basic Emotions’, 177. [↑](#footnote-ref-372)
372. Ekman, 184. [↑](#footnote-ref-373)
373. Ekman, 184–85. [↑](#footnote-ref-374)
374. Ekman, 189. [↑](#footnote-ref-375)
375. Barrett, ‘Are Emotions Natural Kinds?’, 29. [↑](#footnote-ref-376)
376. Scarantino and de Sousa, ‘Emotion’, sec. 8.2; Barrett, ‘Are Emotions Natural Kinds?’, 29. [↑](#footnote-ref-377)
377. Barrett, ‘Psychological Construction’, 379. [↑](#footnote-ref-378)
378. Barrett, 380. [↑](#footnote-ref-379)
379. Barrett, ‘Are Emotions Natural Kinds?’, 31. [↑](#footnote-ref-380)
380. TenHouten, ‘Basic Emotion Theory, Social Constructionism, and the Universal Ethogram’, 613. [↑](#footnote-ref-381)
381. Barrett, ‘Psychological Construction’, 380. [↑](#footnote-ref-382)
382. Lindquist, ‘Emotions Emerge from More Basic Psychological Ingredients’, 357. [↑](#footnote-ref-383)
383. Barrett, ‘Psychological Construction’, 386; Lindquist, ‘Emotions Emerge from More Basic Psychological Ingredients’, 357. [↑](#footnote-ref-384)
384. Barrett, ‘Psychological Construction’, 383. [↑](#footnote-ref-385)
385. TenHouten, ‘Basic Emotion Theory, Social Constructionism, and the Universal Ethogram’, 614. [↑](#footnote-ref-386)
386. Barrett et al., ‘The Experience of Emotion’, 390; Russell, ‘Core Affect and the Psychological Construction of Emotion’, 146. [↑](#footnote-ref-387)
387. Barrett et al., ‘The Experience of Emotion’, 388–89. [↑](#footnote-ref-388)
388. Barrett, ‘Psychological Construction’, 383. [↑](#footnote-ref-389)
389. Barrett and Lindquist, ‘The Embodiment of Emotion’, 250; Lindquist et al., ‘The Brain Basis of Emotion’, 125; Russell, ‘Emotion, Core Affect, and Psychological Construction’, 1264; Schimmack and Grob, ‘Dimensional Models of Core Affect’, 327. [↑](#footnote-ref-390)
390. Dubin and Patapoutian, ‘Nociceptors’, 3760; Kavaliers, ‘Evolutionary and Comparative Aspects of Nociception’, 929. [↑](#footnote-ref-391)
391. Barrett and Lindquist, ‘The Embodiment of Emotion’, 251; Barrett et al., ‘The Experience of Emotion’, 382; Phelps, ‘Emotion and Cognition’, 29. [↑](#footnote-ref-392)
392. Barrett and Lindquist, ‘The Embodiment of Emotion’, 252; Barsalou and Wiemer-Hastings, ‘Situating Abstract Concepts’, 129. [↑](#footnote-ref-393)
393. Barrett and Lindquist, ‘The Embodiment of Emotion’, 251; Barsalou et al., ‘Grounding Conceptual Knowledge in Modality-Specific Systems’, 84. [↑](#footnote-ref-394)
394. Barrett and Lindquist, ‘The Embodiment of Emotion’, 252; Benita et al., ‘Emotion Regulation during Personal Goal Pursuit’, 84; Barrett and Gross, ‘Emotional Intelligence’, 286. [↑](#footnote-ref-395)
395. Barrett and Lindquist, ‘The Embodiment of Emotion’, 252; Keltner and Haidt, ‘Social Functions of Emotions at Four Levels of Analysis’, 506; Levenson et al., ‘Emotion’, 448. [↑](#footnote-ref-396)
396. Barrett and Lindquist, ‘The Embodiment of Emotion’, 252–53; Carr, Kever, and Winkielman, ‘Embodiment of Emotion and Its Situated Nature’, 537–38; Barrett, Lindquist, and Gendron, ‘Language as Context for the Perception of Emotion’, 328. [↑](#footnote-ref-397)
397. Barrett and Lindquist, ‘The Embodiment of Emotion’, 253; Winkielman, Davis, and Coulson, ‘Moving Thoughts’, 1532. [↑](#footnote-ref-398)
398. Haikonen, *The Cognitive Approach to Conscious Machines*, 111–12. [↑](#footnote-ref-399)
399. Barrett et al., ‘The Experience of Emotion’, 388. [↑](#footnote-ref-400)
400. TenHouten, ‘Basic Emotion Theory, Social Constructionism, and the Universal Ethogram’, 611. [↑](#footnote-ref-401)
401. TenHouten, 612. [↑](#footnote-ref-402)
402. Scarantino and Griffiths, ‘Don’t Give Up on Basic Emotions’, 450. [↑](#footnote-ref-403)
403. Scarantino and de Sousa, ‘Emotion’, sec. 11. [↑](#footnote-ref-404)
404. Lindquist et al., ‘The Brain Basis of Emotion’, 130; LeDoux, ‘The Amygdala’, 2007, R873. [↑](#footnote-ref-405)
405. LeDoux, ‘The Amygdala’, 2007, R873. [↑](#footnote-ref-406)
406. Tsigos and Chrousos, ‘Hypothalamic–Pituitary–Adrenal Axis, Neuroendocrine Factors and Stress’, 866–67. [↑](#footnote-ref-407)
407. Fulford and Harbuz, ‘An Introduction to the HPA Axis’, 44. [↑](#footnote-ref-408)
408. Mueller, Figueroa, and Robinson-Papp, ‘Structural and Functional Connections Between the Autonomic Nervous System, Hypothalamic–Pituitary–Adrenal Axis, and the Immune System’, 952–53. [↑](#footnote-ref-409)
409. Mueller, Figueroa, and Robinson-Papp, 953. [↑](#footnote-ref-410)
410. LeDoux, ‘The Amygdala’, 1 August 1994, 234. [↑](#footnote-ref-411)
411. Pester, ‘Humans Are Practically Defenseless. Why Don’t Wild Animals Attack Us More?’; Maron, ‘What to Do If You’re Attacked by a Bear—or Any of These Other Wild Animals’. [↑](#footnote-ref-412)
412. Damasio, ‘The Somatic Marker Hypothesis and the Possible Functions of the Prefrontal Cortex’, 1413. [↑](#footnote-ref-413)
413. Damasio, ‘Emotion and the Human Brain’, 102. [↑](#footnote-ref-414)
414. Maturana and Varela, *Autopoiesis and Cognition*, xvii; Stano et al., ‘Autopoiesis’, 105008. [↑](#footnote-ref-415)
415. Stano et al., ‘Autopoiesis’, 105008. [↑](#footnote-ref-416)
416. Maturana and Varela, *Autopoiesis and Cognition*, iv. [↑](#footnote-ref-417)
417. Luisi, ‘Autopoiesis’, 58. [↑](#footnote-ref-418)
418. Luisi, 52. [↑](#footnote-ref-419)
419. Varela, Maturana, and Uribe, ‘Autopoiesis’, 187. [↑](#footnote-ref-420)
420. Thompson, *Mind in Life*, 96. [↑](#footnote-ref-421)
421. Maturana and Varela, *Autopoiesis and Cognition*, 49. [↑](#footnote-ref-422)
422. Maturana and Varela, 5. [↑](#footnote-ref-423)
423. Maturana and Varela, xix. [↑](#footnote-ref-424)
424. Luisi, ‘Autopoiesis’, 50. [↑](#footnote-ref-425)
425. Varela, Maturana, and Uribe, ‘Autopoiesis’, 188. [↑](#footnote-ref-426)
426. Maturana and Varela, *Autopoiesis and Cognition*, 77. [↑](#footnote-ref-427)
427. Maturana and Varela, 48. [↑](#footnote-ref-428)
428. Maturana and Varela, 73. [↑](#footnote-ref-429)
429. Maturana and Varela, 79. [↑](#footnote-ref-430)
430. Luisi, ‘Autopoiesis’, 51. [↑](#footnote-ref-431)
431. Luisi, 52. [↑](#footnote-ref-432)
432. Luisi, 51; Stano et al., ‘Autopoiesis’, 105008. [↑](#footnote-ref-433)
433. Luisi, ‘Autopoiesis’, 54. [↑](#footnote-ref-434)
434. Luisi, 54; Varela, Maturana, and Uribe, ‘Autopoiesis’, 188. [↑](#footnote-ref-435)
435. Maturana and Varela, *Autopoiesis and Cognition*, 81; Varela, Maturana, and Uribe, ‘Autopoiesis’, 188. [↑](#footnote-ref-436)
436. Varela, Maturana, and Uribe, ‘Autopoiesis’, 189. [↑](#footnote-ref-437)
437. Maturana and Varela, *Autopoiesis and Cognition*, 79. [↑](#footnote-ref-438)
438. Varela, Maturana, and Uribe, ‘Autopoiesis’, 189. [↑](#footnote-ref-439)
439. Luisi, ‘Autopoiesis’, 52; Maturana and Varela, *Autopoiesis and Cognition*, xxiv. [↑](#footnote-ref-440)
440. Luisi, ‘Autopoiesis’, 57. [↑](#footnote-ref-441)
441. Feinberg and Mallatt, ‘Phenomenal Consciousness and Emergence’, 5. [↑](#footnote-ref-442)
442. Feinberg and Mallatt, 6. [↑](#footnote-ref-443)
443. Feinberg and Mallatt, 5. [↑](#footnote-ref-444)
444. Feinberg and Mallatt, ‘The Nature of Primary Consciousness. A New Synthesis’, 118. [↑](#footnote-ref-445)
445. Feinberg and Mallatt, *The Ancient Origins of Consciousness*, 25. [↑](#footnote-ref-446)
446. Feinberg and Mallatt, ‘Phenomenal Consciousness and Emergence’, 7. [↑](#footnote-ref-447)
447. Feinberg and Mallatt, 7. [↑](#footnote-ref-448)
448. Feinberg and Mallatt, *The Ancient Origins of Consciousness*, 51. [↑](#footnote-ref-449)
449. Feinberg and Mallatt, 64. [↑](#footnote-ref-450)
450. Feinberg and Mallatt, ‘Phenomenal Consciousness and Emergence’, 7. [↑](#footnote-ref-451)
451. Feinberg and Mallatt, ‘The Nature of Primary Consciousness. A New Synthesis’, 118; Feinberg and Mallatt, *The Ancient Origins of Consciousness*, 97. [↑](#footnote-ref-452)
452. Feinberg and Mallatt, *The Ancient Origins of Consciousness*, 79. [↑](#footnote-ref-453)
453. Feinberg and Mallatt, ‘The Nature of Primary Consciousness. A New Synthesis’, 118. [↑](#footnote-ref-454)
454. Dawkins, *The Selfish Gene*, 192. [↑](#footnote-ref-455)
455. Mesoudi, ‘Cultural Evolution’, 489. [↑](#footnote-ref-456)
456. Henrich, Boyd, and Richerson, ‘Five Misunderstandings About Cultural Evolution’, 124. [↑](#footnote-ref-457)
457. Varela, Rosch, and Thompson, *The Embodied Mind*, xv. [↑](#footnote-ref-458)
458. Varela, Rosch, and Thompson, 9. [↑](#footnote-ref-459)
459. Varela, Rosch, and Thompson, 3. [↑](#footnote-ref-460)
460. Varela, Rosch, and Thompson, 174. [↑](#footnote-ref-461)
461. Varela, Rosch, and Thompson, 28–29. [↑](#footnote-ref-462)
462. Varela, Rosch, and Thompson, 23. [↑](#footnote-ref-463)
463. Varela, Rosch, and Thompson, 196. [↑](#footnote-ref-464)
464. Varela, Rosch, and Thompson, 151. [↑](#footnote-ref-465)
465. Varela, Rosch, and Thompson, 19; Wheeler, ‘Martin Heidegger’, sec. 2.1. [↑](#footnote-ref-466)
466. Dreyfus, *Being-in-the-World*, 44–45. [↑](#footnote-ref-467)
467. Dreyfus, 24. [↑](#footnote-ref-468)
468. Dreyfus, 2. [↑](#footnote-ref-469)
469. Thompson, *Mind in Life*, xi. [↑](#footnote-ref-470)
470. Thompson, 14. [↑](#footnote-ref-471)
471. Thompson, 37. [↑](#footnote-ref-472)
472. Thompson, 153. [↑](#footnote-ref-473)
473. Thompson, 74. [↑](#footnote-ref-474)
474. Thompson, 410. [↑](#footnote-ref-475)
475. Shapiro and Spaulding, ‘Embodied Cognition’, sec. 1.2; Thompson, *Mind in Life*, 10. [↑](#footnote-ref-476)
476. Luisi, ‘Autopoiesis’, 50. [↑](#footnote-ref-477)
477. Wiener, *Cybernetics*, 18. [↑](#footnote-ref-478)
478. Wiener, 18. [↑](#footnote-ref-479)
479. Heylighen and Joslyn, ‘Cybernetics and Second-Order Cybernetics’, 157. [↑](#footnote-ref-480)
480. Ashby, *An Introduction to Cybernetics*, 1. [↑](#footnote-ref-481)
481. Heylighen and Joslyn, ‘Cybernetics and Second-Order Cybernetics’, 155. [↑](#footnote-ref-482)
482. Heylighen and Joslyn, 156. [↑](#footnote-ref-483)
483. Heylighen and Joslyn, 160. [↑](#footnote-ref-484)
484. Johnston, *The Allure of Machinic Life*, 26. [↑](#footnote-ref-485)
485. Heylighen and Joslyn, ‘Cybernetics and Second-Order Cybernetics’, 156. [↑](#footnote-ref-486)
486. Wiener, *Cybernetics*, 62. [↑](#footnote-ref-487)
487. Wiener, 131. [↑](#footnote-ref-488)
488. Wiener, 132. [↑](#footnote-ref-489)
489. Hasan, ‘Comparative Study of Watt, Porter, Proell and Hartnell Governor Mechanism’, 481. [↑](#footnote-ref-490)
490. Hasan, 482. [↑](#footnote-ref-491)
491. Black, ‘Stabilized Feedback Amplifiers’, 5. [↑](#footnote-ref-492)
492. Hofstadter, *I Am a Strange Loop*, 54. [↑](#footnote-ref-493)
493. Wiener, *Cybernetics*, 130. [↑](#footnote-ref-494)
494. Wiener, 12. [↑](#footnote-ref-495)
495. Wiener, *The Human Use of Human Beings*, 68. [↑](#footnote-ref-496)
496. Wiener, 68–69. [↑](#footnote-ref-497)
497. Wiener, 69. [↑](#footnote-ref-498)
498. Johnston, *The Allure of Machinic Life*, 165. [↑](#footnote-ref-499)
499. Johnston, 54. [↑](#footnote-ref-500)
500. Johnston, 165–66. [↑](#footnote-ref-501)
501. Johnston, 169. [↑](#footnote-ref-502)
502. Johnston, 170. [↑](#footnote-ref-503)
503. Bays, ‘Introduction to Cellular Automata and Conway’s Game of Life’, 4. [↑](#footnote-ref-504)
504. Johnston, *The Allure of Machinic Life*, 171–72. [↑](#footnote-ref-505)
505. Johnston, 173. [↑](#footnote-ref-506)
506. Varela, *Principles of Biological Autonomy*; Johnston, *The Allure of Machinic Life*, 188. [↑](#footnote-ref-507)
507. Johnston, *The Allure of Machinic Life*, 189. [↑](#footnote-ref-508)
508. Johnston, 198. [↑](#footnote-ref-509)
509. Brooks, ‘Artificial Life and Real Robots’, 3. [↑](#footnote-ref-510)
510. Brooks, 4. [↑](#footnote-ref-511)
511. Harvey et al., ‘Evolutionary Robotics’, 80. [↑](#footnote-ref-512)
512. Brooks, ‘Artificial Life and Real Robots’, 9. [↑](#footnote-ref-513)
513. Brooks, 3–4. [↑](#footnote-ref-514)
514. Brooks, 6. [↑](#footnote-ref-515)
515. Johnston, *The Allure of Machinic Life*, 197. [↑](#footnote-ref-516)
516. Johnston, 198. [↑](#footnote-ref-517)
517. Johnston, 198; Bourgine and Varela, ‘Toward a Practice of Autonomous Systems’, xi. [↑](#footnote-ref-518)
518. Bourgine and Varela, ‘Toward a Practice of Autonomous Systems’, xi. [↑](#footnote-ref-519)
519. Johnston, *The Allure of Machinic Life*, 200. [↑](#footnote-ref-520)
520. Johnston, 200. [↑](#footnote-ref-521)
521. Bedau, ‘Artificial Life’, 296. [↑](#footnote-ref-522)
522. Johnston, *The Allure of Machinic Life*, 347–48. [↑](#footnote-ref-523)
523. Dreyfus, ‘Alchemy and Artificial Intelligence’. [↑](#footnote-ref-524)
524. Dreyfus, 61–62. [↑](#footnote-ref-525)
525. Dreyfus, *What Computers Still Can’t Do*, xi. [↑](#footnote-ref-526)
526. Dreyfus, xi–xii. [↑](#footnote-ref-527)
527. Dreyfus, *What Computers Can’t Do*, 215. [↑](#footnote-ref-528)
528. Dreyfus, *What Computers Still Can’t Do*, iv. The contents of this publication are almost identical to its older version titled *What Computers Can’t Do*. In the “Introduction to the MIT Press Edition” on page ix, Dreyfus states that this edition “marks not only a change of publisher and a slight change of title; it also marks a change of status. The book now offers not a controversial position in an ongoing debate but a view of a bygone period of history.” [↑](#footnote-ref-529)
529. Dreyfus, xlv. [↑](#footnote-ref-530)
530. Dreyfus, xlv–xlvi. [↑](#footnote-ref-531)
531. Dreyfus, xii. [↑](#footnote-ref-532)
532. Bedau, ‘Artificial Life’, 297. [↑](#footnote-ref-533)
533. Pollack et al., ‘Three Generations of Automatically Designed Robots’, 216. [↑](#footnote-ref-534)
534. Bongard, Zykov, and Lipson, ‘Resilient Machines Through Continuous Self-Modeling’, 1118. [↑](#footnote-ref-535)
535. Young, ‘A General Architecture for Robotics Systems’, 238. [↑](#footnote-ref-536)
536. Young, 259. [↑](#footnote-ref-537)
537. ‘Faculty & Staff’. Dr. Haikonen is listed under the heading ‘Adjunct Faculty’ and has supplied his curriculum vitae which includes his tenure as Principal Scientist at the Nokia Research Center. [↑](#footnote-ref-538)
538. Haikonen, *Consciousness and Robot Sentience*, 42. [↑](#footnote-ref-539)
539. Haikonen, 6. [↑](#footnote-ref-540)
540. Varela, Rosch, and Thompson, *The Embodied Mind*, 41. [↑](#footnote-ref-541)
541. Haikonen, *Consciousness and Robot Sentience*, 4. [↑](#footnote-ref-542)
542. Krause et al., *An Introduction to Psychological Science*, 93. [↑](#footnote-ref-543)
543. Krause et al., 94. [↑](#footnote-ref-544)
544. Krause et al., 96. [↑](#footnote-ref-545)
545. Krause et al., 97. [↑](#footnote-ref-546)
546. Krause et al., 98. [↑](#footnote-ref-547)
547. Gottesmann, ‘GABA Mechanisms and Sleep’, 235. [↑](#footnote-ref-548)
548. Hebb, *The Organization of Behavior*, 62. [↑](#footnote-ref-549)
549. Krause et al., *An Introduction to Psychological Science*, 23. [↑](#footnote-ref-550)
550. Haikonen, *Consciousness and Robot Sentience*, 90. [↑](#footnote-ref-551)
551. Krause et al., *An Introduction to Psychological Science*, 21. [↑](#footnote-ref-552)
552. Haikonen, *Robot Brains*, 17. [↑](#footnote-ref-553)
553. Haikonen, *Consciousness and Robot Sentience*, 90. [↑](#footnote-ref-554)
554. Haikonen, ‘XCR-1’, 361. [↑](#footnote-ref-555)
555. Haikonen, *Consciousness and Robot Sentience*, 92. [↑](#footnote-ref-556)
556. Haikonen, ‘XCR-1’, 361. [↑](#footnote-ref-557)
557. Haikonen, *Robot Brains*, 45. [↑](#footnote-ref-558)
558. Haikonen, 19. [↑](#footnote-ref-559)
559. Haikonen, 20. [↑](#footnote-ref-560)
560. Haikonen, 20. [↑](#footnote-ref-561)
561. Haikonen, *Consciousness and Robot Sentience*, 94. [↑](#footnote-ref-562)
562. Haikonen, *Robot Brains*, 46. [↑](#footnote-ref-563)
563. Haikonen, *Consciousness and Robot Sentience*, 216. [↑](#footnote-ref-564)
564. Haikonen, 118. [↑](#footnote-ref-565)
565. Haikonen, *Robot Brains*, 19; Haikonen, *Consciousness and Robot Sentience*, 118. [↑](#footnote-ref-566)
566. Haikonen, ‘XCR-1’, 362; Haikonen, *Robot Brains*, 72–73. [↑](#footnote-ref-567)
567. Haikonen, ‘XCR-1’, 363. [↑](#footnote-ref-568)
568. Haikonen, *Robot Brains*, 72–73. [↑](#footnote-ref-569)
569. Haikonen, ‘XCR-1’, 362. [↑](#footnote-ref-570)
570. Haikonen, *Consciousness and Robot Sentience*, 114. [↑](#footnote-ref-571)
571. Haikonen, *Robot Brains*, 180. [↑](#footnote-ref-572)
572. Haikonen, *Consciousness and Robot Sentience*, 155. [↑](#footnote-ref-573)
573. Haikonen, *Robot Brains*, 180. [↑](#footnote-ref-574)
574. Haikonen, ‘XCR-1’, 362; Haikonen, *Robot Brains*, 104–5. [↑](#footnote-ref-575)
575. Haikonen, *Robot Brains*, 100. [↑](#footnote-ref-576)
576. Haikonen, 105. [↑](#footnote-ref-577)
577. Haikonen, 101. [↑](#footnote-ref-578)
578. Haikonen, *Consciousness and Robot Sentience*, 129. [↑](#footnote-ref-579)
579. Haikonen, *Robot Brains*, 85. [↑](#footnote-ref-580)
580. Haikonen, 86. [↑](#footnote-ref-581)
581. Murari et al., ‘Which Photodiode to Use’, 753. [↑](#footnote-ref-582)
582. Haikonen, ‘XCR-1’, 363. [↑](#footnote-ref-583)
583. Haikonen, *Consciousness and Robot Sentience*, 211–12. [↑](#footnote-ref-584)
584. Haikonen, *Robot Brains*, 152. [↑](#footnote-ref-585)
585. Haikonen, ‘XCR-1’, 364. [↑](#footnote-ref-586)
586. Haikonen, *Robot Brains*, 152. [↑](#footnote-ref-587)
587. Haikonen, ‘XCR-1’, 364. [↑](#footnote-ref-588)
588. Haikonen, *Robot Brains*, 154. [↑](#footnote-ref-589)
589. Haikonen, 154. [↑](#footnote-ref-590)
590. Haikonen, 155. [↑](#footnote-ref-591)
591. Haikonen, 156. [↑](#footnote-ref-592)
592. Haikonen, 82. [↑](#footnote-ref-593)
593. Haikonen, 87. [↑](#footnote-ref-594)
594. Haikonen, 83. [↑](#footnote-ref-595)
595. Haikonen, 83. [↑](#footnote-ref-596)
596. Haikonen, 180. [↑](#footnote-ref-597)
597. Haikonen, *Consciousness and Robot Sentience*, 159. [↑](#footnote-ref-598)
598. Haikonen, *Robot Brains*, 180. [↑](#footnote-ref-599)
599. Haikonen, 181. [↑](#footnote-ref-600)
600. Haikonen, 182. [↑](#footnote-ref-601)
601. Haikonen, *Consciousness and Robot Sentience*, 159. [↑](#footnote-ref-602)
602. Haikonen, 160–61. [↑](#footnote-ref-603)
603. Haikonen, *Robot Brains*, 153. [↑](#footnote-ref-604)
604. Haikonen, 149. [↑](#footnote-ref-605)
605. Haikonen, *Consciousness and Robot Sentience*, 156. [↑](#footnote-ref-606)
606. Haikonen, *Robot Brains*, 79. [↑](#footnote-ref-607)
607. Haikonen, 141. [↑](#footnote-ref-608)
608. Haikonen, 140–41. [↑](#footnote-ref-609)
609. Haikonen, 142. [↑](#footnote-ref-610)
610. Haikonen, 140. [↑](#footnote-ref-611)
611. Haikonen, 142. [↑](#footnote-ref-612)
612. Haikonen, 143. [↑](#footnote-ref-613)
613. Haikonen, ‘XCR-1’, 361. [↑](#footnote-ref-614)
614. Haikonen, *Consciousness and Robot Sentience*, 138. [↑](#footnote-ref-615)
615. Haikonen, 139. [↑](#footnote-ref-616)
616. Haikonen, *The Cognitive Approach to Conscious Machines*, 214. [↑](#footnote-ref-617)
617. Haikonen, *Robot Brains*, 156. [↑](#footnote-ref-618)
618. Haikonen, *The Cognitive Approach to Conscious Machines*, 223. [↑](#footnote-ref-619)
619. Haikonen, 229. [↑](#footnote-ref-620)
620. Haikonen, 231. [↑](#footnote-ref-621)
621. Haikonen, 236–37. [↑](#footnote-ref-622)
622. Haikonen, 219–20. [↑](#footnote-ref-623)
623. Haikonen, *Robot Brains*, 162. [↑](#footnote-ref-624)
624. Haikonen, 163. [↑](#footnote-ref-625)
625. Haikonen, 162; Haikonen, *Consciousness and Robot Sentience*, 207–8. [↑](#footnote-ref-626)
626. Haikonen, *Consciousness and Robot Sentience*, 208. [↑](#footnote-ref-627)
627. Haikonen, *Robot Brains*, 163. [↑](#footnote-ref-628)
628. Haikonen, *The Cognitive Approach to Conscious Machines*, 220. [↑](#footnote-ref-629)
629. Youtube, ‘Pentti Haikonen’. See https://www.youtube.com/@PenHaiko for a list of videos. [↑](#footnote-ref-630)
630. *Calling Robot by Name Feat. Sound Direction Detection*. [↑](#footnote-ref-631)
631. *Robot Sequence Memory*. [↑](#footnote-ref-632)
632. *Robot Self-Consciousness. XCR-1 Passes the Mirror Test*. [↑](#footnote-ref-633)
633. Moudatsou et al., ‘The Role of Empathy in Health and Social Care Professionals’, 3. [↑](#footnote-ref-634)
634. de Waal and Preston, ‘Mammalian Empathy’, 498. [↑](#footnote-ref-635)
635. Gallagher, ‘The Practice of Mind. Theory, Simulation or Primary Interaction?’, 90–91. [↑](#footnote-ref-636)
636. Gallagher, ‘Neurons, Neonates and Narrative’, 174; Gallagher, ‘The Practice of Mind. Theory, Simulation or Primary Interaction?’, 99. [↑](#footnote-ref-637)
637. Dreyfus, *What Computers Still Can’t Do*, xlv–xlvi. [↑](#footnote-ref-638)
638. Harnad, ‘Other Bodies, Other Minds’, 46. [↑](#footnote-ref-639)
639. Clarke, ‘Divorce Left Me Struggling to Find Love. I Found It in an AI Partner’. [↑](#footnote-ref-640)