

İSTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

**A HISTORICAL EVALUATION OF ARTIFICIAL INTELLIGENCE WITH
FOCUS ON
ALGORITHMS GENERATING CREATIVE ARTWORK**



Ph.D. THESIS

İlkem Ahu ŞAHİN

Department of History of Science and Technology

History of Science and Technology Programme

FEBRUARY 2026

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**İlkem Ahu ŞAHİN
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Thesis Advisor: Prof. Dr. Aytekin ÇÖKELEZ

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

**YAPAY ZEKA ÜZERİNE YARATICI YAPIT ÜRETEEN ALGORİTMALAR
ODAKLI TARİHSEL BİR DEĞERLENDİRME**

DOKTORA TEZİ

**İlkem Ahu ŞAHİN
(422202001)**

Bilim ve Teknoloji Tarihi Bölümü

Bilim ve Teknoloji Tarihi Programı

Tez Danışmanı: Prof. Dr. Aytekin ÇÖKELEZ

ŞUBAT 2026

İlkem Ahu ŞAHİN, a Ph.D. student of ITU Graduate School student ID 422202001, successfully defended the thesis/dissertation entitled “A HISTORICAL EVALUATION OF ARTIFICIAL INTELLIGENCE WITH FOCUS ON ALGORITHMS GENERATING CREATIVE ARTWORK”, which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor : **Prof. Dr. Aytekin ÇÖKELEZ**
Istanbul Technical University

Jury Members : **Prof. Dr. Tuncay ZÖRLÜ**
Istanbul Technical University

Assoc. Prof. Dr. Burak BARUTÇU
Istanbul Technical University

Asst. Prof. Dr. Kaan ATA
Istanbul University

Asst. Prof. Dr. Taha Yasin ARSLAN
Istanbul Medeniyet University

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To my family,





Everything must have a beginning, to speak in Sanchean phrase; and that beginning must be linked to something that went before. The Hindoos give the world an elephant to support it, but they make the elephant stand upon a tortoise. Invention, it must be humbly admitted, does not consist in creating out of void, but out of chaos; the materials must, in the first place, be afforded: it can give form to dark, shapeless substances, but cannot bring into being the substance itself. In all matters of discovery and invention, even of those that appertain to the imagination, we are continually reminded of the story of Columbus and his egg. Invention consists in the capacity of seizing on the capabilities of a subject, and in the power of moulding and fashioning ideas suggested to it.

Mary Shelley, *Frankenstein* (1831, p.xii)



FOREWORD

This dissertation is the culmination of a journey fueled by an inquisitive mind, perpetually driven by a passion for diverse fields of knowledge. It represents the careful balance achieved through disciplined and dedicated effort alongside a professional career, made possible by the trust and opportunities extended by the academic community. Crucially, it stands as a testament to the understanding and support of family, the encouragement of friends, and the transformative impact of the pandemic in realizing deferred aspirations.

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As an individual pursuing a doctorate in the social sciences with an engineering background, I profoundly experienced the synergy of interdisciplinary approaches and endeavored to fruitfully integrate these positive influences into my research. In this regard, I must gratefully acknowledge the esteemed faculty of the Computer Engineering Department at Boğaziçi University, who laid the conceptual foundations of artificial intelligence during my undergraduate studies—the very subject around which my core thesis is built. Furthermore, the lecturers who guided my postgraduate work at Berlin Technical University significantly contributed to advancing this understanding.

My sincere thanks go to my cherished mother, father, and all family members. Their continuous encouragement of my intellectual curiosity, coupled with their remarkable understanding and patience as my personal time was significantly redirected towards this thesis, was absolutely essential. I believe this graduation will be a source of great relief and pride for them as well.

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To the reader, I hope this thesis offers a meaningful contribution to the exploration of the historical origins of artificial intelligence and, particularly, the methodical processes underlying creativity. More importantly, I aspire for this work to modestly contribute to interdisciplinary collaboration and research, and to serve as an encouraging source of inspiration for anyone with a commitment to learning and pursuit of contributing to the academic world.

February 2026

İlkem Ahu ŞAHİN
Computer Engineer

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ABBREVIATIONS

ACM	: Association for Computing Machinery
AD	: Anno Domini
AI	: Artificial Intelligence
ANN	: Artificial Neural Network
App	: Appendix
ASCC	: Automatic Sequence Controlled Calculator
BBN	: Bayesian Belief Network
BC	: Before Christ
CPU	: Central Processing Unit
(D)ARPA	: The (Defense) Advanced Research Projects Agency
DSRPAI	: Dartmouth Summer Artificial Intelligence Research Project
EDVAC	: Electronic Discrete Variable Automatic Computer
ENIAC	: Electronic Numerical Integrator and Computer
IPL	: Information Processing Language
LISP	: List Processing (Language)
MIT	: Massachusetts Institute of Technology
PHD/PH.D.	: Philosophiae Doctor
RUR	: Rossum's Universal Robots
UNIVAC	: Universal Automatic Computer
UNESCO	: United Nations Educational, Scientific and Cultural Organization
US/ USA	: United States/ United States of America
WWW	: World Wide Web



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A HISTORICAL EVALUATION OF ARTIFICIAL INTELLIGENCE WITH FOCUS ON ALGORITHMS GENERATING CREATIVE ARTWORK

SUMMARY

The practice of history writing begins with the understanding and acknowledgment that the past cannot be completely reconstructed as it was. The trajectory of artificial intelligence (AI), the subjective agency of this dissertation, originates in the ancient efforts of humanity to emulate nature, and eventually intelligence on inanimate objects. This enduring fascination was driven by various motivations, primarily, by the desire to explain natural phenomena of the universe and the complex functioning of living organisms and the mind. The continual historical narrative of AI has been shaped by the mutual influence of diverse disciplines over time, propelled by strategic research and development during the Second World War, and eventually, AI was conceptually formalized as a field in the middle of the twentieth century. This dissertation aims to critically evaluate the existing historical accounts of artificial intelligence and compile them into a structured narrative, and subsequently uncover the origins of creativity within the context of AI.

The mechanistic world view, promoted by the Scientific Revolution, significantly influenced the development of automata and subsequent technological advancements. The history of AI is appreciated as continuation of this intellectual and technological narrative. The research in AI was inspired by arguments in philosophy and shaped by the conceptual discussions and formalizations in mathematics as a science. AI as an interdisciplinary field adapted theories from physics and was developed in interaction with psychology and linguistics. Eventually, the implementation of artificial intelligence was constrained by the technological capabilities and their inherent limitations prevalent at the time.

Mathematics and physics were foundational in the establishment of artificial intelligence's theoretical framework. Development of formal systems, probability theory, concept of randomness, and arguments and proofs leading to the incompleteness of mathematics were influential. In physics, the theories of thermodynamics, primarily entropy, that influenced information theory, contributed to foundational thoughts about data and artificial intelligence. The concept of uncertainty, as established in physics, notably in quantum mechanics, anticipated a paradigm shift in artificial intelligence, moving from deterministic to probabilistic approaches. Moreover, the brain modeling theory that emerged in the early twentieth century, proposed the vision that neural networks were heterogeneous systems of neurons.

During the mid-20th century, the concept of the intelligent machine gained prominence. The advent of the computer provided the essential platform for realizing

the aspiration of implementing humanoid intelligence. Study shows that the story of artificial intelligence is an accumulation and assimilation of progressing events rather than a set of abrupt shift and sudden discontinuity over time. Nevertheless, the emergence of AI as a separate discipline is commonly related to the 1956 Dartmouth College conference event where the term artificial intelligence was officially used for the first time. The conference's proposal outlined specific problems to be addressed and key areas in the field of AI for future investigation. Since then, AI research and implementation technologies have progressed through multiple distinct phases. From the middle of the twentieth century, artificial intelligence was implemented based on symbolic manipulation, expert-systems databases, and data-driven machine learning approaches.

The ability to process and utilize aesthetic elements differentiates human cognition from machine intelligence. Inspired by this assertion, building upon a comprehensive compilation of diverse AI historical narratives, this dissertation subsequently focused on the domain of artificial creativity, a topic that was central during the emergence of AI to the debate on whether machines can think. In this context, a conceptual exploration of creativity and its place within the field of artificial intelligence was performed.

Creativity, a foundational feature of human intelligence, is widely related to aspects of chance, chaos, randomness, and unpredictability. The nascence of computer-generated arts coincides with the emergence of mainframe computers in the 1950s. Cybernetics and information aesthetics concepts influenced early art production experiments by the computer during 1960-70s.

To discover whether computational creativity was implemented based on a common approach, early AI approaches across diverse creative domains of music composition, painting and poetry were examined. The emergence and development of computer creativity is evaluated within the broader context of AI history and in connection with the art movements. Contemporary approaches to artificial creativity are additionally examined to link historical accounts to future trajectories.

Analysis across various creative domains revealed that early computer poetry, digital visual arts and music composition were implemented using similar underlying principles. In particular, a random generator was used in all fields to activate a few of the many interaction options within a system with defined boundaries, given inputs, and defined interaction rules, and as a result obtaining unpredictable but calculable outputs. The concepts of information aesthetics, inspired by cybernetics and information theory, were applied. Experiments were influenced by mathematical methods of stochastic and random algorithmic implementations. The computer was used as a laboratory environment to experiment with the formalized processes of innate human creativity. Researchers in each of the three domains selected for this study were exploring the creative processes and working on their algorithmic formalization. In the early experiments, rule-based algorithms were widely used. Pioneering research sought to elucidate the procedural mechanisms utilized by individuals during the creative process, rather than to produce outcomes of significant aesthetic or artistic value. Nevertheless, the endeavors contributed to the foundation of subsequent creative artificial intelligence models.

This study was conducted following qualitative historical research. The research is based on textual analysis of published archival and contemporary literature and serves an interpretive approach. Critical interpretation of primary and secondary sources was

performed. The research centered on the middle of the twentieth century, a pivotal period marked by the conceptual emergence of AI. Nevertheless, to maintain the integrity of the overarching historical account, foundational preceding concepts in the history of artificial intelligence are introduced in the report. The study concludes with an analysis of current state-of-the-art developments to establish a seamless historical narrative.





YAPAY ZEKA ÜZERİNE YARATICI YAPIT ÜRETEN ALGORİTMALAR ODAKLI TARİHSEL BİR DEĞERLENDİRME

ÖZET

Tarih yazımına başlarken, geçmişin bütünüyle ve tamamen olduğu gibi yeniden canlandırılmayacağına dair bir farkındalık ve bilinç oluşturulmalıdır. Bu tez çalışması, yapay zeka (YZ) öznel olgusu etrafında tarihsel gerçeklerin araştırılmasına dayalı bir anlatı olarak kurgulanmıştır.

Evren ve yaşama dair döngülerin insanlar için antik dönemlerden itibaren merak konusu olduğu tarihsel izlerle gözlemlenmektedir. Yapay zekanın geçmiş yolculuğu, insanlığın bu döngüler ve bilişsel süreçleri çözümüyle merakını cansız nesneler üzerinde mekanizmalar geliştirerek taklit etme çabalarına dayandırılabilir. Temel olarak, insanın doğal fenomenleri, biyolojik ve zihinsel döngüleri anlama arzusu ve yaşamın prensiplerine dair hiç sönmeyen ilgisi bu uğraşları çağlar boyu canlı tutmuştur. Kitleleri eğlendiren mekanik oyuncaklar üretmek ve insanlara hizmet ederek günlük yaşamı daha verimli kılan aletler geliştirmek, söz konusu icatların geliştirilmesindeki diğer önemli motivasyonlar arasında yer almışlardır.

Yapay zekanın temelleri zaman içerisinde farklı bilimsel disiplinlerle etkileşim halinde şekil almıştır. İkinci Dünya Savaşı sırasındaki stratejik adımlarla beraber hız kazanan bilimsel ve teknolojik araştırmaların da etkisiyle YZ kavramsal olarak yirminci yüzyılın ortalarında tanımlanmıştır. Bu tez çalışmasının temel ereği, yapay zeka hakkında literatürde yer alan mevcut tarihsel anlatıları eleştirel bir bakış açısıyla değerlendirerek bütüncül bir anlatı içerisinde yeniden yapılandırmak ve devamında tezin odağında yer alan algoritma ile yaratıcı yapıt üretme çabalarının temellerini YZ tarihi bağlamında araştırıp ortaya çıkarmaktır. Bu doğrultuda, tez raporu, yapay zeka hakkında tarihsel bir derleme ve yapay yaratıcılık üzerine akademik araştırmaya dayalı özgün bir bakış açısı ortaya koymaktadır.

Bu araştırmada, YZ hakkında literatürde yer alan farklı tarihsel anlatılar sentezlenerek altı başlıkta yapılandırılmıştır. Başlıca, kökenleri mekanik dünya görüşüne dayanan, disiplinler arası bir alan olan, gelişimi bilgisayarların tarihiyle eşzamanlık gösteren, yirminci yüzyılın ortalarında ayrı bir alan olarak tanımlanan, dönemsel başarı ve başarısızlıklarıyla farklı mevsimlerden geçen, ve önemli olaylarıyla kronolojik olarak özetlenen yapay zeka anlatıları derlenmiş ve rapor kapsamında sunulmuştur.

Bilimsel Devrim tarafından teşvik edilen mekanik dünya görüşü, otomatların ve müteakip teknolojik gelişmelerin ilerlemesini önemli ölçüde etkilemiştir. Yapay zeka tarihi de bu entelektüel ve teknolojik tarih birikiminin bir devamı olarak yorumlanabilir. Yapay zekanın önünü açan araştırmalarda felsefe alanındaki argümanlardan esinlenilmiş ve YZ matematik bilimindeki kavramsal tartışma ve biçimselleştirme çabalarından etkilenerek şekil almıştır. YZ bilimler ve disiplinler

arası bir alan olarak fizik kökenli önerilen teorileri uyarlamış ve benzer şekilde psikoloji ve dilbilimdeki gelişmelerden etkilenmiştir. Yapay zekanın hayata geçirilmesi ise dönemin sunduğu teknolojik kabiliyet ve imkanlar doğrultusunda mümkün kılınırken, teknolojik kısıtlarla da sınırlı kalmıştır.

Matematik ve fizik, yapay zekanın teorik çerçevesini oluşturmada temel rol üstlenmişlerdir. Biçimsel sistemlerin, olasılık teorisinin, rastgelelik kavramının ve matematiğin eksikliğiyle sonuçlanan argümanların ve ispatların gelişimi YZ'nin kavramsal olarak ortaya atılması ve çerçevelendirilmesi üzerinde etkili olmuştur. Yirminci yüzyılın başlarında, matematikçiler bir ispatı geçerli kılanın ne olduğunu tanımlamanın yollarını arıyor ve bu amaçla matematiksel temelleri araştırıyorlardı. David Hilbert karar problemini (Entscheidungsproblem) bu bağlamda sunmuştur. Matematiğin biçimsel bir sistem olarak önerilmesi Kurt Gödel tarafından eksiklik teoremleriyle eleştirel bir şekilde sorgulanmış, Alan Turing ise Gödel'den farklı olarak, evrensel makineyi fikir olarak icat etmiş ve bu kavramsal makineyi kullanarak, belirli bir formülün fonksiyonel hesaplama aralığında kanıtlanabilir olup olmadığını belirlemek için genel bir yöntemin bulunmadığını ve dolayısıyla matematiğin karar verilemez olduğunu göstermiştir. Turing, teorik olarak mantıksal bir sistem içinde her hesaplanabilir işlemi gerçekleştiren bir algoritmanın varlığını kanıtlamıştır.

Fizik alanında termodinamik yasaları, özellikle bilgi teorisini de etkileyen entropi kavramı, veri ve yapay zeka hakkındaki temel fikirlere katkı sağlamışlardır. İstatistiksel mekanikte tanımlanan entropi kavramı, Claude Shannon tarafından önerilen Bilgi Teorisi'nin temel taşlarından birini oluşturmuştur. Shannon, yirminci yüzyılın ortalarında sürdürdüğü çalışmalarında genel bir iletişim teorisi tanımlamayı hedeflemiştir. Bu çalışması, bilgi teorilerini, nihayetinde veri kavramını ve bunlara dayanan yapay zeka yaklaşımlarını etkilemiştir. Bunun yanı sıra fizikte, özellikle de kuantum mekaniğinde ortaya konan belirsizlik kavramı, yapay zekada deterministik yaklaşımlardan olasılığa dayalı yaklaşımlara doğru bir paradigma değişimini öngörmüştür.

Yirminci yüzyılın ilk yarısında, davranışçı psikoloji ekolünde zihin-makine metaforu yaygınlaşmaya başlamıştır. Makineler ile insan beyni arasındaki benzerlikler, bilim insanları için bir araştırma alanı haline gelmiştir. Nöroloji ile iş birliği içinde yürütülen psikoloji çalışmaları, beyin fonksiyonlarının modellenmesi ve öğrenmedeki sinaptik nöron eyleminin önemi üzerine varsayımların ortaya atılmasıyla sonuçlanmıştır. YZ çalışmalarını da etkileyen beyin modelleme teorisi, sinir ağlarının heterojen nöron sistemleri olduğu vizyonunu öne sürmüştür. Yüzyılın ortalarına gelindiğinde Alan Newell ve Herb Simon bilişsel süreçlerin bilgisayar simülasyonları üzerinde deneyler yaparken, Noam Chomsky teorik dilbilimi yeniden tanımlayarak bilişsel bir devrim başlatmıştır. Chomsky, insan dilini tanımlamak için içsel temsiller içeren üretimsel dilbilgisi gibi bir teorinin gerekli olduğunu savunarak dil alanında biyolojiden matematiğe kadar uzanan yeni araştırma boyutlarının oluşumunu doğrudan etkilemiştir. Dil alanındaki biçimselleştirme çabaları, YZ ve makine çevirisi araştırmalarına zemin hazırlamıştır.

Yirminci yüzyılın ortalarında akıllı makine kavramı gitgide önem kazanmıştır. Bilgisayarların icadı, insansı zekanın uygulamaya geçirilmesi temennisini gerçekleştirmek için ihtiyaç duyulan temel platformu sağlamıştır.

Yapay zekanın tarihi, kesintili bir akış yerine zaman içerisinde gelişen olayların birikimi ve özümsemesiyle örülü bir hikayedir. Bununla beraber tarihte belirgin bir olay, 1956 yılındaki Dartmouth Koleji Konferansı, yapay zekanın ayrı bir disiplin

olarak doğuşunu sembolize eder. “Yapay zeka” ifadesinin resmi olarak ilk defa bu etkinlikte kullanıldığı bilinmektedir. Konferansın öneri metninde, o dönem için gelecekteki yapay zeka çalışmalarının odaklanması tavsiye edilen araştırmaya açık alanlar listelenip detaylandırılmıştır. YZ alanındaki bu ilk çalışmayı takiben çeşitli yaklaşımlar izlenmiştir. Yirminci yüzyılın ortalarından itibaren, yapay zeka sembolik manipülasyon, uzman sistem veri tabanları ve veriye dayalı makine öğrenimi modelleri temelinde uygulamaya geçirilmiştir.

Estetik unsurları işleme ve kullanma yeteneği, insan bilişini makine zekasından ayırtıran temel özellikler arasındadır. Araştırma, bu savdan esinlenerek ve yapay zeka tarihine ilişkin farklı anlatıların kapsamlı bir derlemesini temel alarak, YZ’nin ortaya çıktığı dönemde makinelerin düşünebilme yeteneği üzerine olan tartışmanın merkezinde yer alan yapay yaratıcılık konusuna odaklanmıştır. Bu bağlamda, yaratıcılık teması kavramsal olarak ve yapay zeka alanındaki konumu itibarıyla irdelenmiştir.

İnsan zekasının temel alameti farikalarından kabul edilen yaratıcılık kabiliyeti, yaygın bir şekilde şans, kaos, rastgelelik ve öngörülemezlik ile ilişkilendirilir. Bilgisayar tabanlı sanatın doğuşu, ana bilgisayarların ortaya çıktığı 1950’lerle eşzamanlıdır. Sibernetik ve bilgi estetiği kavramları da 1960-70’li yıllardaki bilgisayar ile yaratıcı sanat oluşturmaya amaçlayan öncü deneyleri etkilemiştir. 1960’larda Bilgi Estetiği, rasyonel ve objektif bir estetik teorisi tanımlama girişimi olarak disiplinler arası bir yaklaşımla ortaya çıkmıştır. Bu yaklaşım, estetiğin objektif ölçütlerini matematiksel temellere dayandırmak için Shannon’ın Bilgi Teorisi’ni referans almıştır. Akıma Avrupa’da iki akademik merkez olarak Almanya’da Max Bense ve Fransa’da Abraham Moles liderlik etmişlerdir.

Tez çalışması özelinde, yapay zeka ile sanat üretimi yolculuğunun ilk örneklerinde yaratıcılığın ne olduğuna dair ortak bir kavrayışın var olup olmadığı sorgulanmıştır. Bu keşif çabası, çalışmanın odaklandığı tarihsel dönem olarak yirminci yüzyıl ortalarında gerçekleştirilen YZ tabanlı yaratıcı ürün geliştirme deneylerinin çıkış noktalarını ve algoritmik yaklaşımlarını inceleyerek sürdürülmüştür. Araştırma kapsamında incelenecek alanlar olarak müzik besteleme, resim ve şiir üretimi yaratıcı süreçleri seçilmiş ve bu alanlardaki erken yapay zeka yaklaşımları, sanat dalları arasında uygulanan ortak ve ayrık metotları keşfetmek amacıyla karşılaştırmalı olarak ele alınmıştır. Algoritma tabanlı yaratıcı sanat üretiminin temelleri, daha bütüncül yapay zeka tarihi kapsamında ve dönemsel sanat hareketleri ile de bağlantı kurularak değerlendirilmiştir. Ek olarak, geçmiş ve gelecek arasında bir köprü kurabilmek adına daha güncel sanal yaratıcılık yaklaşımları da mercek altına alınmıştır.

Müzik, resim ve şiir alanlarındaki YZ yaklaşımlarını tarihsel bakış açısıyla ele alan bu çalışmanın analizi sonucunda, erken dönem bilgisayar ile üretilen şiir, dijital görsel sanatlar ve müzik kompozisyonunun benzer prensiplerle hayata geçirilmiş oldukları tespit edilmiştir. Özellikle, tanımlanmış sınırlar, belirli girdiler ve tanımlanmış etkileşim kurallarına sahip bir sistem içerisinde, birden fazla etkileşim seçeneğinden bir kaçını etkinleştirmek amacıyla her üç alanda da bir rastgele üreteç mekanizması kullanılmış ve bu sayede öngörülemeyen ancak hesaplanabilir çıktılar elde edilmiştir. Ayrıca, sibernetik ve bilgi teorisinden esinlenen bilgi estetiği kavramları uygulanmıştır. Bilgisayar tabanlı deneyler, bilgi teorisi ile stokastik ve rastgelelik temelli algoritmik uygulamaların matematiksel yöntemlerinden etkilenmiştir. Bilgisayar deneysel bir platform; insanın bilişsel yaratıcı süreçlerini irdelemek için bir laboratuvar olarak kullanılmıştır.

İnceleme alanı olarak seçilen her üç sahada da YZ araştırmacılarının insanın yaratıcı sanat üretme süreçlerini çözümleme merakıyla bunların algoritmik biçimlendirmeleri üzerinde çalışmakta oldukları gözlemlenmiştir. Öncü deneylerde kural-tabanlı algoritmalar geniş çapta kullanılmıştır. Yirminci yüzyılın ortasındaki araştırmalarda, estetik veya sanatsal değeri yüksek sonuçlar üretmekten ziyade, bireylerin yaratıcı süreç boyunca kullandıkları yönetsel mekanizmaların açıklanması amaçlamıştır. Alandaki bu öncü çalışmalar, tarihsel süreçte onları takip eden yaratıcı yapay zeka geliştirme modellerinin temellerini inşa etmede etkin olmuşlardır.

Tez çalışması, nitel tarihsel araştırma yöntemine uygun olarak gerçekleştirilmiştir. Araştırma, yayınlanmış arşivlerin ve güncel literatürün metin analizine dayanmakta olup, yorumlayıcı bir yaklaşım sunmaktadır. Birincil ve ikincil kaynakların eleştirel yorumu yapılmıştır. İncelemeler, yapay zekanın kavramsal olarak ortaya çıktığı kilit dönem kabul edilen yirminci yüzyılın ortalarını merkeze alarak sürdürülmüştür. Kapsamlı tarihsel anlatının bütünlüğünü korumak amacıyla, bu döneme hazırlık oluşturan temel öncül kavramlar ile güncel gelişmeler arasında da bir bağlantı kurulmuş ve anlatı kapsamında kaleme alınmıştır. Bu yaklaşım, geçmişten günümüze uzanan metodolojik akışı bütüncül bir perspektifle sunmayı hedeflemektedir.

Yirmi birinci yüzyılın ilk çeyreğinde, yapay zeka teknolojileri genellikle "dar" veya "zayıf yapay zeka" olarak adlandırılan alana özgü uygulamalarla sınırlı kalmıştır. Gelecekte tam insan zekasını taklit etmesi beklenen makineler ise "genel yapay zeka" veya "güçlü yapay zeka" kategorisi altında sınıflandırılmaktadır. Gelişmekte olan teknolojiler arasında sayılan yapay zeka, birçok farklı alanda olduğu gibi dijital sanat üretmek için de makine öğrenimi metodolojilerinin çeşitli varyasyonlarını kullanmaktadır. Makine öğrenimi kavramları, 1940'larda önerilen nöron tabanlı modellerden köken almıştır. Zamanla geliştirilen yaklaşımlar, veri odaklı sistemlere dönüşmüştür. Derin öğrenme, derin yapay sinir ağlarına dayanan bir makine öğrenimi türüdür. Potansiyelleriyle beraber, yapay zeka ve yaratıcı alandaki uygulamaları, gelecek için gelişime açık fırsatları barındırmaya devam etmektedir.

1. INTRODUCTION

The practice of history writing begins with the understanding and acknowledgment that the past cannot be completely reconstructed as it was. According to Dahlhaus (1983), the historical narration is feasible upon discovering a "subjective agency" within the historical processes that preserves its identity despite changing circumstances. This agency ensures uninterrupted continuity and thereby safeguarding our perception of the past from fracturing into disparate, unrelated elements.

In this dissertation work, the intelligent machine is identified as the subjective agency. Concerning the period starting from the conceptualization of artificial intelligence (hereafter AI) in the mid-20th century, the agency is referred to as AI in the narrative. Despite the lack of a standard definition about what AI is and what it covers, a 2019 description by the European Commission refers to it as follows:

Artificial intelligence (AI) systems are software (and possibly also hardware) systems designed by humans that, given a complex goal, act in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information, derived from this data and deciding the best action(s) to take to achieve the given goal. AI systems can either use symbolic rules or learn a numeric model, and they can also adapt their behaviour by analysing how the environment is affected by their previous actions. (Samoili:2020, p.4)

The scientific study of intelligence reveals that it is a complex and multifaceted concept, which presents considerable challenges in terms of both its definitive characterization and empirical measurement (Hiser and Francis, 2000). Human intelligence has traditionally served as the primary benchmark for machine intelligence. Although computers may surpass human computational abilities, humanoid intelligence is characterized by complex and multifaceted mental processes

exhibited by individuals at the level of sophistication that is precisely what artificial intelligence endeavors to achieve.

The historical trajectory of artificial intelligence originates in the ancient efforts of humanity to simulate intelligence on inanimate objects. This ongoing historical narrative has been shaped by the mutual influence of diverse social and natural science disciplines, propelled by strategic research and development during the Second World War, and eventually, AI was conceptually formalized as a field in the middle of the twentieth century. This dissertation aims to provide a comprehensive understanding of AI's emergence and development by synthesizing diverse historical perspectives and compiling them into a structured narrative. In the first part, following an introduction to the conceptual background of intelligence, the history of AI is organized and detailed in the dissertation body under six complementary headings:

- i. *AI originating from the mechanistic world view on inanimate objects* explores the origins of AI, illustrated by the ancient efforts to simulate intelligence in inanimate objects
- ii. *Interdisciplinary foundations of the artificial intelligence* details the historical progress across the diverse disciplinary research fields that influenced AI's emergence and development
- iii. *History of AI as part of the computer history* integrates AI history with computer history, asserting that the emergence of computers provided the necessary platform for the implementation of artificial intelligence
- iv. *Emergence of AI as a separate discipline* concentrate on the mid-20th century, a period during which AI was formalized as a distinct research field
- v. *AI seasons in the history* provides an overview of the fluctuations in AI's development over time
- vi. *A chronological summary of AI* chronologically outlines key events in the history of artificial intelligence

Creativity is cited as a key feature that distinguishes human intelligence from its of machine counterpart (Arf, 1959). Inspired by this assertion, this dissertation specifically explores the history of artificial creativity, a topic that was central during the emergence of AI to the debate on whether machines can think. Following the

compilation of diverse narratives pertaining to AI history, the next part of the study introduces AI algorithms and problem-solving approaches utilized throughout the twentieth century. Subsequently, creativity concepts relevant within the AI context are explored under the following headings:

- AI Approaches Throughout The Twentieth Century
 - Evolution of artificial intelligence algorithms
 - AI problem solving strategies
- Understanding The Emergence of AI Creativity
 - Creativity as a concept and in relevance to AI
 - Computational creativity

This research work questions whether a common understanding of creativity as formalized and implemented by the machine existed in the early years of AI. In this purpose, early computer-based music composition, painting and poetry history is explored for commonalities in AI implementation approaches across these three diverse creative domains. Finally, contemporary approaches to artificial creativity implementation are examined to establish a continuous perspective from historical development to future trajectories:

- Under the heading *Comparative Analysis Of Early Computer-based Music Composition, Painting And Poetry Algorithms*, music composition by computer, digital visual arts and digital poetry during the emergence of AI are explored
- *Comparative analysis* aims discovering commonalities in the understanding of creativity by exploring the implementation approaches across these three diverse creative domains
- Before concluding the dissertation, *State Of The Art: Creative Algorithms* section bridges the historical narrative to the future trajectories

1.1 Purpose Of Thesis

This study examines the origins of artificial intelligence along with the concept of creativity. In this context, the thesis study has two main objectives.

Primary purpose is to critically evaluate existing historical accounts of artificial intelligence. This will involve systematically analyzing the diverse narratives and compiling them through the different lenses of identified conceptual pillars, resulting in a structured synthesis of the field's evolution. The research centers on the middle of the twentieth century, a pivotal period marked by the conceptual emergence of AI. This focal point of study is analyzed to establish a historical bridge between the predating foundations and to trace AI's subsequent evolution.

The other purpose is to uncover the underlying mechanisms of creativity implemented through AI algorithms. In this context, a conceptual exploration of creativity and its place within the field of artificial intelligence will be performed. The historical background of AI approaches and algorithms will be presented. Analysis will further draw upon studies from creative fields of music composition, visual arts, and digital poetry to understand the motivations triggering early computer-generated creative works and identify common approaches in underlying algorithms. The emergence and evolution of computer creativity is evaluated within the broader context of AI history and in connection with the art movements. Eventually, the overall research will synthesize whether unique definition of creativity as accepted within the AI field during the early twentieth century implementations, can be identified.

The ultimate goal of the dissertation work is to significantly contribute to existing literature by compiling diverse historical narratives of artificial intelligence and uncovering the origins of algorithmic creativity within the context of AI.

1.2 Materials And Methods

This dissertation was prepared following historical research methodologies from the fields of science and technology and intellectual history. The research is based on textual analysis of published archival and contemporary literature and serves a qualitative and interpretive approach. Critical interpretation of primary and secondary sources was performed.

The history of artificial intelligence was explored by examining publications through academic journals, portals and thesis centers related to the field. These are detailed in the Literature Review section. Consequently, the review on the existing literature led to the determination of the research scope, by identifying areas for further investigation and significant scholarly contribution.

The collected material was utilized for tracing the development of intellectual concepts and technologies over time in the history of AI and computer creativity. After having determined the purpose and identified concerning research questions, a thorough study of the primary and secondary publications including archival sources was conducted. Different perspectives and approaches for the focal historical period were compared and analyzed. The analysis of the study findings was leveraged to perform a synthesis. Findings were interpreted within the broader inter-disciplinary context of artificial intelligence and creativity.

In the beginning, a thematic basis was introduced for the study by investigating diverse definitions of “intelligence”. Subsequently, the outcomes of the exploration of the generic history of science and technology related to AI, the genesis of the mechanistic world view, the journey of automatons throughout the centuries, the emergence of computers, and twentieth century developments in diverse disciplines contributing to the conceptualization of artificial intelligence as an interdisciplinary field, were presented. The diverse historical narratives of the artificial intelligence were synthesized and compiled with AI as an interdisciplinary field rooted on concepts like automata and conceptually defined during mid period of the twentieth century.

Literature review suggested creativity as a core feature of intelligence. The concept of creativity and the emergence of its implementation in the field of artificial intelligence was investigated as part of three different fields of arts: music composition, visual arts, and digital poetry. In this context, sources including primary literature from leading historical figures across various scientific and artistic backgrounds was referenced and critically analyzed. The findings of the analysis were synthesized to identify whether a consistent definition or understanding of creativity was evident during the AI-art production in the twentieth century and to explore underlying motivation for the early experiments.

1.3 Literature Review

The topic of this dissertation work was determined after having conducted a comprehensive literature review in the history of artificial intelligence. In this purpose, academic journals, portals, and thesis centers related to the history of science and technology were explored and resulting publications reviewed.

The journals referred to at the beginning of the literature review were primarily *Isis – A Journal of the History of Science Society* and *Osiris* by the University of Chicago Press, *The British Journal for the History of Science* and *BJHS Themes* by the Cambridge University Press. As next, portals such as Google Scholar and DergiPark Academic were used for keyword scanning. Moreover, the National Thesis Center of the Council of Higher Education (YÖK Ulusal Tez Merkezi) was used to scan thesis work already published in the related fields.

Sample keywords that were used to scan literature are “history of artificial intelligence”, “emergence of computers”, “automata history”, “history of algorithms”, “artificial intelligence and arts”, “intelligence as a concept”, “creativity as a concept”, “history of creativity”, “history of intelligence”, “artificial intelligence algorithms”, “algorithmic art”, “computer-based music production”, “history of algorithmic painting”, “computer-generated poetry”, and “theoretical development of artificial intelligence”. While exploring existing publications with the help of the keywords, scientific work of the leading researchers in the field and of those who played a historical role in the development of artificial intelligence were identified and corresponding primary literature was examined.

Outcomes of the literature review were used to determine the dissertation topic. In this context, historical primary sources as well as more recent articles, book chapters and reports were reviewed. An area open to research and publication at the intersection of artificial intelligence and creativity was identified as a result.

Among the literature reviewed is the article titled “Intelligence: A Brief History” by Hiser and Francis (2000), which examines how the expression “intelligence” has been used throughout history. The “Computing Machinery And Intelligence” by Alan Turing (1950) is the revolutionary article that introduces the Imitation Game in response to the query of whether machines can think and is one of the primary documents to refer in the AI history. The primary documents are valuable sources for

capturing the developments and perspectives of the period in which they were written. Cahit Arf's conference report, Arf (1959), was published during the same period in the history and provides further insight into machine thinking in the mid-twentieth century, when discussions of artificial intelligence were just beginning to develop. Sari (2021) analyses Arf's article based on a philosophical perspective supported by additional literature. Mijwel (2015) summarizes key milestones in the history of artificial intelligence and McCorduck et al. (1977) similarly provides a brief view about the evolution of artificial intelligence by the second half of the twentieth century. Allen Newell's report, Newell (1982), dates back to the second half of the century and contributes to the historical debates around intellectual issues in the field of AI. The paper also covers an interesting debate about the act of writing "the history" of science. Kayaönü (2000) provides the results of a master's thesis about the theoretical background of artificial intelligence. The study explores the question of whether it is possible to simulate the human mind from the perspective of different sciences, including biology, mathematics, and computer science. Weak and strong AI approaches are characterized by questioning the ability of humans to understand and model themselves. Cimilli (2021), another master's thesis about the historical background of AI, provides a reference to the philosophical discussions about consciousness and language processing. Hazar (2022), is a Ph.D. thesis report that examines the universality of artificial intelligence in terms of the programming languages. In this purpose, a historical analysis of the universality of languages is performed throughout the 20th century, starting from the time of Leibniz. Erkıran (2022) introduces the development of machine learning from a historical and philosophical perspective as part of a master's thesis. The process of learning of human and machine is elaborated within philosophical framework. The Ph.D. thesis of Bayık (2022), compares human mental processes and artificial intelligence, and provides a summary about historical and ethical debates in the field. Kapır (2022) studies artificial intelligence and algorithmic systems through a historical perspective within the context of society and media, in a Ph.D. thesis. Apart from that, the master's thesis of Adanur (2022) about new media and that of Atıktürk (2022) about the internet of things are research publications on the evolution of artificial intelligence within the context of media. Şahinci (2021) studies as part of a Ph.D. thesis the historical development of artificial intelligence and big data and the impacts of digitalization on marketing. In

this context, issues related to the creativity of AI is being addressed. Sarı (2022) narrows the scope of the discussion to whether AI can think critically, going back to Alan Turing's original question. To this end, standards for testing this question have been proposed and applied to a previously developed AI system.

Haenlein and Kaplan (2019) explains the history of artificial intelligence as a four-season story, with its ups and downs, starting with the birth of AI in the mid-twentieth century. The story is formulated based on seven published articles with different perspectives on the subject. The essay covers the past and present of AI and concludes with a view on the future. Penn (2020) presents the results of a comprehensive Ph.D. thesis work on the history of information processing and artificial intelligence in the United States during the middle period of the 20th century. Dick (2015) is about the discovery of the implementation of an abstract model of human reasoning into a program for the JOHNNIAC computer by Herbert Simon and his colleagues between 1955 and 1957. Following this implementation, the paper argues that "internal" cognitive practices and "external" tools and materials are not as easily separated as in Simon's principle of bounded rationality.

Bell (2018) is an article about the interaction of humans and robots in the context of culture and technology from a historical perspective. Aytaş (2012) is a thesis that deals with the analysis of the "Mechanical Turk", a fraudulent chess-playing machine from the eighteenth century. The study explores the long-term relationship between the rise of intelligent automatons (the technological "Other" of the European mind) and the rise of Western discourses of Orientalism (the cultural "Other"), converging in the concept of the mechanized mind that is argued to have become active in the cybernetic devices of the twentieth century and the distributed cognitive labor platforms of the early twenty-first century. Stephens (2022) compares the eighteenth century Mechanical Turk and the contemporary Amazon microjob platform of the same name. The article argues that both machines embrace technological hoax although in a different setup. In the Mechanical Turk from the past, a human was hidden inside the machine for directing the chess play. In the contemporary version of this, it is stated that behind the digital environment that is assumed to be fully automatic, human cognitive labor operates and for this reason this system is called 'artificial' artificial intelligence.

The literature review also encompassed publications focusing on the concept of creativity and creative algorithms during the emergence of AI, in addition to its historical overview.

Existing academic research explores the multifaceted interaction between technology and art in certain context. Başaran (2007) investigates this relationship within the context of the twentieth century, particularly its relevance to Futurism and Cyberpunk. Bodur (2015) focuses on the influence of motion, the role of mechanical systems and machines in generating artwork throughout the twentieth century. The master's thesis Ergün (2019) also investigates the interaction between technology and art. It begins with an introduction to the history of artificial intelligence before exploring AI's impact on artistic domains. Examples of artwork generated by AI across graphics, music, painting, and literature and a forecast about the future of AI in these fields are presented. The study explores distinctive characteristics that differentiate human artists from AI and highlights that the contemporary AI-generated art relies on big data and the copies of existing works. Based on that, the creativity of introduced by AI is questioned. The master thesis Paksın (2020) assesses the relationship between artificially produced and human made artwork to evaluate the distinctions between creativity and the appearance of creativity. Within this context, history of artificial intelligence is elaborated.

The question of whether artificial intelligence can demonstrate creativity has long inspired field of arts. The research by Şen (2022) addresses AI's potential capacity for creativity in character design within the context of an applied project to investigate this. AI's creative capabilities are examined using diverse datasets with a practical project to explore the boundaries and potential. Aydoğan (2021) is a dissertation about the impacts of digitalization within the field of art. The shift fundamentally transforms art especially through virtual reality systems that change the traditional concepts of "reality" by exploring new layers of it leading to timeless, spaceless, and objectless production and interaction. Bülbül (2021), another PhD research work, investigates how Big Data transforms our perception and the boundaries of art. The aim of the study is to explore the conceptual, art-historical, philosophical, and epistemological consequences of this paradigm in a multifaceted way.

Çelebi (2021) interrogates the evolving relationship and interaction between machines, eventually artificial intelligence, and art from the twentieth century to the present. The

historical use of machines in art and conceptual shifts they inspired over time and ultimately the twenty-first century technological advancements are analyzed. Girão and Santos (2019) present an in-depth analysis prepared for the European Parliament about the historical and contemporary relationship of art and technology development. The growing art-technology collaborations and underlying models are explored, and art is promoted thereby as a crucial driver of knowledge generation and innovation in addition to its cultural contribution. Yakın (2021) is a master thesis that studies the machine's evolution throughout the history with a particular focus on how human existence is transformed by the integration of artificial intelligence. In this regard, AI's future role with its potential benefits and harms is explored by analyzing the portrayal of AI in science fiction cinema.

Kurt (2018) studies artificial intelligence as an artistic phenomenon and analyses algorithm-produced artifacts to construct a theoretical and philosophical basis for the creative abilities of AI. Finally, an alternative conceptual definition of art is being proposed considering AI acting as an artistic and creative agent.

The paper by McCormack and d'Inverno (2014) analyses current research questions concerning computers and creativity and calls for a re-evaluation of the concept of creativity. Computers are not seen as only tools but are becoming creative agents and collaborative partners. Wang (2019) on the other hand advocates for the subjective value of art promoting human artistic uniqueness during the age of AI. Accordingly, although AI transforms artistic paradigms and values, these are not radical. It is argued that in the foreseeable future AI produced art cannot replace human artistic value. The research report by Artut (2019) examines the widespread integration of artificial intelligence into daily life and its increasing interaction with art. AI's development, its relationship with creativity and impact on contemporary art is elaborated.

The essay of Hertzmann (2018) questions the creative capacity of artificial intelligence by comparing it with other technological advancements in history like photography that initially met resistance from the public. Contemporary impact of AI in arts and future potentials are discussed. The paper argues in the end that AI systems cannot be credited with the authorship of artwork based on our current understanding.

The remainder of this review examines existing literature on the historical development of creative algorithms in the fields of music composition, painting, and poetry.

The dissertation by Burns (1994) examines the history and development of algorithms in musical composition from 1957 to 1993, with relevance to computer science, information science, and music theory and composition. Broad definition of related algorithms and analysis of algorithmic compositions along with the key musical compositions and literature from the period are included. The Ph.D. thesis by Spiers (2020) presents the examination of relationship between the material body and immaterial mind by mechanical music generation throughout the history. Accordingly, the "spectacle of music" in machines was used to simulate and assess both physical performance and the embodied cognitive experience of music. Eventually, a musical history of science is presented starting from enlightenment automata and android musicology to the present artificial intelligence. The article, Doornbusch (2017), documents preliminary computer music experiments dating to middle of the twentieth century in parallel to developments of early computers. The earliest known instances of computers playing music were conducted in Australia and England using the CSIRAC, Ferranti Mark 1, and Pilot ACE computers and followed by the initiatives in the U.S. Bell Laboratories. Verma (2021) summarizes the historical milestones of artificial intelligence in the field of music. AI is utilized for composition, production, performance, marketing, and consumption of music. AI can respond to live musicians in interactive applications that synchronize with human performers. Voice recognition and natural language processing for music control is used in various player programs.

The paper Egido (2021) introduces a series of Artificial Computer Creativity (ACC) techniques rooted in Collaborative Intelligence (CI) from an interdisciplinary perspective applied in music. Turing Test is re-evaluated by the article, proposing alternative validation metrics. The master thesis of York (2019) evaluates the status of AI in music generation by reviewing papers of the Musical Metacreation (MUME) conferences. Accordingly, various approaches to AI development are identified: Turing or acting humanly, cognitive or thinking humanly, logic or thinking rational, and agent or acting rational approach. A shift towards cognitive approaches by 2012 is observed in the musical AI. It is stated that the development of a universal computer

function to evaluate “good” quality AI-generated music remains a challenge across all approaches.

The Ph.D. thesis by Parlak (2021) illustrates that algorithms to create music and fine arts have been developed throughout the history and in alignment with the rise of the computers. Although Western music has been composed with Deep Learning-based artificial composers, Turkish Makam Music remained unexplored. The study addresses this gap by introducing the Automatic Turkish Makam Music Composer (ATMMC) as an open-source system to generate Turkish Makam compositions.

Voulodimos et al. (2017) reviews key developments in deep learning architectures- Convolutional Neural Networks, Deep Boltzmann Machines, Deep Belief Networks, and Stacked Denoising Autoencoders- and explores their applications in computer vision tasks. A historical as well as future perspective is provided including benefits and limitations of the architectures and challenges in the field.

Mantaras (2016) presents the concepts of computational creativity as an emerging field within AI that is aiming human-like creative activities such as music composing, poetry writing, in visual arts as well as providing collaboration tool for human artists. It is argued that creativity can be scientifically studied and simulated by the computer.

Prehistoric Digital Poetry documented by Funkhouser (2007) offers an archaeological study about the historical development of the digital poetry archive from 1959 to 1995. The transition from early stages to the establishment of digital poetry is illustrated. The outcome contributes both to research on digital poetry as well as to the broader theoretical discussions on contemporary literary production.

Existing academic literature on the history of artificial intelligence and algorithms, particularly concerning creativity, only partially addresses the comprehensive scope intended for this thesis. An analysis tracing the historical evolution of AI implementation approaches in music composition, painting, and poetry will effectively illuminate the trajectory of computational creativity.

1.4 Hypothesis

This dissertation about the emergence and historical development of artificial intelligence and the concepts of creativity within the realm of AI history was framed

by several hypotheses. The outcomes of the research pursue validating these propositions:

- I. The trajectory of artificial intelligence represents an ongoing narrative rather than an interrupted historical account.
- II. AI originates from humanity's ancient effort to simulate intelligence on inanimate objects and the mechanistic world view.
- III. AI as a field has been shaped by the mutual influence of diverse social and natural science disciplines and conceptually formalized as a field in the middle of the twentieth century.
- IV. AI was propelled by strategic research and development during the Second World War.
- V. Creativity as an indication of human intelligence was central during the emergence of AI to the debate on whether machines can think.
- VI. The question of whether AI can demonstrate creativity has inspired the field of arts and scientific experiments. An analysis tracing the historical evolution of AI implementation approaches in music composition, painting, and poetry can illuminate the trajectory of computational creativity.
 - i. Analysis will demonstrate whether common understanding of creativity existed while formalizing for computer implementation.
 - ii. It will present the motivations behind the early experiments in computer creativity.
 - iii. The interaction of technological developments and art movements will be demonstrated by the analysis.

These hypotheses will be examined by a critical historical analysis utilizing primary and secondary literature. Key concepts, paradigms shifts, pivotal events, interdisciplinary influences, technological advances, and their practical implications will be investigated in the history of AI intersecting creativity. Eventually, by the historical evidence provided throughout the thesis, the propositions will be validated or refuted. This practice will overall contribute to a comprehensive understanding of the multi-faced history of artificial intelligence and algorithmic creativity.



2. HISTORICAL NARRATIVES OF ARTIFICIAL INTELLIGENCE

2.1 Intelligence As A Concept

Intelligence, as studied by the different fields of science, is a multifaceted and vague concept that is difficult to define and measure. The general cognitive skill of problem-solving ability that can be applied to all situations or disciplines can be referred as intelligence. It is assumed that Cicero was considering this type of general definition while suggesting the term *intelligentia* and introduced the concept of what is now called intelligence (Hiser and Francis, 2000).

A variety of views to conceptualize and find a definition for the term were submitted by the numerous experts to an issue of the Journal of Educational Psychology in 1921 (Hiser and Francis, 2000). The efforts in defining the concept of and metrics to measure intelligence continued during the second half of the twentieth century. Resulting definitions proposed that "intelligence is what intelligence tests measure" and "the general ability of an individual to perform complex mental processing that involves conceptualisation and the transformation of information" would address intelligence (Hiser and Francis: 2000, p.124).

The etymology of the term "artificial" is derived from a synthesis of two Latin roots: the noun *ars* (or *artis*), which denotes specialized skill as seen in the roles of the artist and artisan, and the verb *facere*, meaning "to make". Accordingly, the phrase *artificial intelligence* denotes the type of intelligence that is made by the skilled effort (Luger, 2021). According to a more contemporary definition, artificial intelligence is "a system's ability to interpret external data correctly, to learn from such data, and to use those learnings to achieve specific goals and tasks through flexible adaptation" (Haenlein and Kaplan:2019, p.1)¹.

In the context of machines, humanoid intelligence has been accepted as the main indicator of intelligence. A computer's calculation ability can be superior to a human being, yet humanoid

¹ The author refers to ESCP Europe Business School while quoting the definition of artificial intelligence

intelligence is identified by the multifaceted complex mental processing of an individual which is the level of sophistication that artificial intelligence aims. Alan Turing did not attempt to find a definition for intelligence while questioning whether machines could think in his foundational paper of 1950, the Computing Machinery and Intelligence. Instead, he introduced the *imitation game* test to verify the intelligence of a machine, in terms of the *thinking* ability of a machine that is successfully pretending like a human being who is thinking (Turing, 1950). Accordingly, Turing was attributing intelligence to inanimate objects which can imitate human intelligence to a level that is indistinguishable from the original, without trying to define what intelligence is, which remains a vague concept.

The middle of the twentieth century is recognized as a turning point in the history of artificial intelligence when events took place where the field was conceptually defined and key problems to research were proposed. The origins of AI however date back to much earlier in the history. This dissertation considers the history of AI as a cumulative story of scientific and social developments and proposes different narratives of it as part of the overall history.

2.2 Historical Narratives Of Artificial Intelligence

The historical trajectory of artificial intelligence originates in humanity's ancient effort to simulate intelligence on inanimate objects. This ongoing narrative has been shaped by the mutual influence of diverse social and natural science disciplines, propelled by strategic research and development during the Second World War, and conceptually formalized as a field in the middle of the last century.

In this section, the diverse historical narratives on artificial intelligence will be compiled and presented in an integrated manner. Emergence of artificial intelligence as an outcome of the mechanistic world view, the historical development of artificial intelligence as an interdisciplinary field and key events leading to its conceptual definition, the story of AI that is equated to the story of computers, AI ups-and-downs described by seasons and a chronological narrative of important milestones in the AI history will be provided.

2.2.1 AI originating from the mechanistic world view on inanimate objects

The concept of mechanization stems from the Greek word *mechane* (instrument) and relates to the replacement of labor conducted by human or animal by the machines. The term mechanical can be associated to multifaced meanings from the basic meaning of *activity conducted with instruments* to the related field in physics that explore the *motion of material objects*. Apart from these, *automated activities* or *activities that are conducted in an unthinking manner* are also called mechanical and are typically characterized with the inanimateness of a machine (Mul, 1999).

Attempts to mimic intelligence on inanimate objects date back to prior to the development of Greek civilization. Pictorial representations with automation existed long before. From a scientific perspective, mechanistic world view has been an attempt to explicate the natural universe of physics and biology. The innate urge of humankind to explain the nature from a mechanistic view led to the development of automata; devices that move by themselves. Technological artifacts were designed by capturing certainty and regularity in nature to explain the motions of planets and the behavior of living creatures (Price, 1964). Objects that were designed to simulate features that are attributed to living things were studied by the philosophical systems and have significantly affected cultural themes over the time (Siciliano and Khatib, 2019).

The sixteenth and seventeenth centuries are commonly referred as the era of Scientific Revolution that is considered to have taken place in Europe. This was a period where scientific experimentation was promoted and mathematical descriptions to the inorganic natural events were explored. The period did not only influence natural sciences; moreover, together with the machine technology linked to them the outcomes of the period impacted the industrialization of Western society in the long term (Mul, 1999).

Automatons had their golden age in Europe and Asia during the eighteenth century (Siciliano and Khatib, 2019). Apart from simulating living systems by the mechanistic view to explain their underlying processes, automatons were designed to serve humans and help them in their work and efforts. They were also entertaining societies by their extraordinary look and capabilities (Voskuhl, 2018). These devices are acknowledged as the ancestors of the Industrial Revolution. The progress with automatons impacted the progress in technology covering fine

mechanism and scientific instrumentation. It is accepted that automatons eventually transformed throughout the centuries and evolved into today's emerging technologies (Price, 1964; Voskuhl, 2018).

2.2.1.1 Mechanization of the body

Greek mythology features numerous artificial intelligences or automata, that were brought together to be useful or to perform a task that the mythological figures themselves found difficult. Mentioned by Homer around 850 BC, Hephaestus, the ugly and disabled fire god and divine smith, according to legend, created servants to help him walk and work in his furnace. "These are golden, and in appearance like living young women. There is intelligence in their hearts, and there is speech in them and strength, and from the immortal gods they have learned how to do things." (McCorduck et al., 1977, p. 1). The automaton statue Talos, created by Hephaestus, is another example of the mythological creatures that could move on their own and serve humans (Gök and Gülaçtı, 2024).

Hellenistic engineers were among the pioneers of automation design. The conquest of Asia by Alexander in the second half of the fourth-century BC generated a multicultural creative environment based on the Greek, Asiatic, and Egyptian scientific and technical skills. Alexandria became the capital of the new Hellenistic culture where the Museum and the Library, that remained the largest of the world for centuries, was established. The first known head of the Museum, the engineer Ctesibius of third-century BC, owns the first book written on pneumatics. His inventions included an advanced water clock to solve the problem of decreasing flow rates based on the first feedback control system and hydroacoustic automata such as the hydraulic pipe organ. The great Alexandrian polymath Heron (circa 10–70 AD) was the inventor of a theater automaton operating based on hidden effects of water or steam. The Alexandrian discoveries of automation and mechanical power by pressure, water and steam were lost until they were rediscovered a millennium and a half later, with the dispersion of Hellenistic culture in the early Christian era (Guarnieri, 2010).

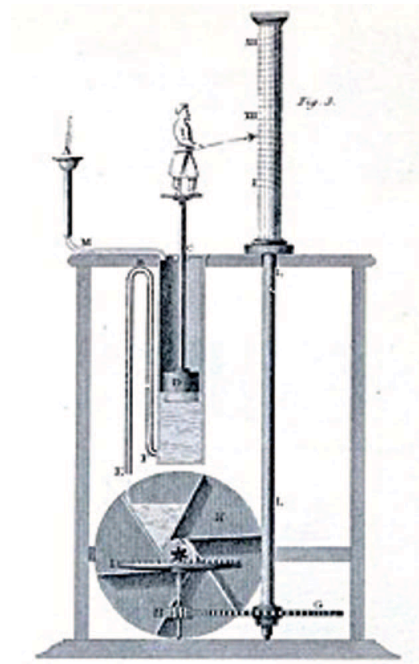


Figure 2.1 : Ctesibius' water clock adapted from (Guarnieri: 2010, p. 1).

During the period called the Golden Age of Islam, which extended from the eighth to the thirteenth centuries, many great philosophers and scholars such as Ibn Sina, Ibn Rushd, and Al-Kindi appeared in the history of humankind, and their works influenced the development of Western philosophy and science. It is known that Islamic technicians had built wind-powered automata for the Abbasid Caliphs of Baghdad. Ebu'l-Izz bin Rezzaz el-Cezeri (Al-Jazari, 1136 – 1206), the medieval polymath and pioneering engineer is well known by his inventions of complex machines and mechanical devices. In 1206, he described in *The Book of Knowledge of Ingenious Mechanical Devices* fifty devices and forms of machinery including water clocks, automata, and various other complex technical devices of his design. Al-Jazari's inventions included four musicians on a boat with changing facial and body actions according to musical selection and an automated elephant clock that was striking a cymbal every hour or half hour. The advanced machines that Al-Jazari built predate the first primitive mechanical clocks in Europe by decades and hold an important place in the pioneering history of automata (Bir, 1977; Guarnieri, 2010; Kaplan, 2023).



Figure 2.2 : Serving Automata Designed by Al-Jazari, adapted from (Gök and Gülaçtı: 2024, p. 214).

In the fifteenth century, the automatons became more mechanized, and the first modern measuring machines and mechanical clocks were designed. Humanoid automatons are observed in Leonardo da Vinci's designs. Around 1495, da Vinci designed an automaton in the form of a warrior in medieval armor, now known as *Leonardo's robot*. It is not known whether this automaton, thought to have been designed for entertainment, was actually built or merely remained a sketchbook drawing. However, a machine recently constructed from the original drawings has been proven to be fully functional as Leonardo had planned (Gök and Gülaçtı, 2024; Guarnieri, 2010).

The craft tradition and the printed book of the Scientific Revolution of the sixteenth and seventeenth centuries influenced sophistication of the design of astronomical and biological automata. Nuremberg and Augsburg emerged as craft centers of skilled clock and instrument makers (Price, 1964). The *clock* as a metaphor was used in the seventeenth and eighteenth centuries for the mechanistic interpretations of the nature. That was a paradigmatic example based on the machine technologies of the time (Mul, 1999).

Aristotle's physics, which forms the basis of the Renaissance theories, attributed movement to the living being itself or to an external effect arising from it. Newtonian physics described motion as a mathematical concept and broke this ancient legacy. Cartesian dualism also supported this later approach. Accordingly, while soul could not be defined by matter or

movement; body's material existence and mobility were like a machine. In his work *Leviathan*, the English philosopher Thomas Hobbes argued that the human body resembled an automaton with its organs working like machines. Seventeenth century's perspective considered machines and automatons as movable objects. Descartes distinguished between real human and artificial objects by the help of this approach. Although inanimate objects could also move; the mind and the ability to think remained unique to humans (Gök and Gülaçtı, 2024; Sunar, 2020).

Automatons of the eighteenth century were much more sophisticated in terms of the mechanical complexity and expertise in comparison to the former and later century samples of inanimate objects. Besides, they are remarkable as indicators of the approaching industrial revolution (Voskuhl, 2018).

During the eighteenth century's Enlightenment when rational world view flourished; La Mettrie compared human being to a machine that was regulated by the rules of the mechanics. Nevertheless, human was a living subject of volitional and conscious activity. Everything else than the subject was an object and may existed as an imperfect equivalent of the original subject. Eighteenth-century automata were designed in terms of their production material and working principles based on an approach that imitated living beings both in the internal structures of the objects as well as on their visible external surfaces. La Mettrie's belief, that supported the victory of human reason over the nature in making living being like mechanisms possible, was reflected into the real automatons of their contemporary inventors like Jacques de Vaucanson and Wolfgang von Kempelen (Sunar, 2020).

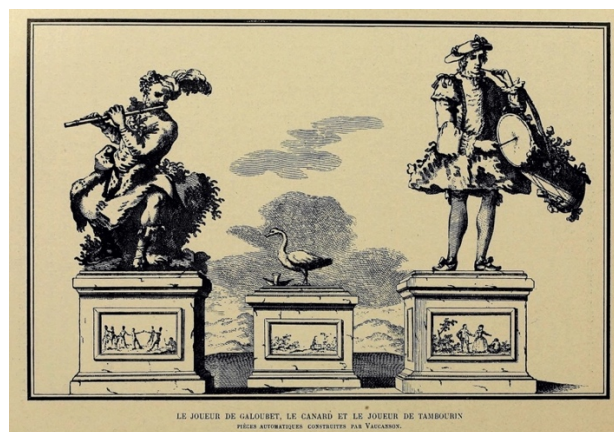


Figure 2.3 : Vaucason's Automatons, adapted from (Sunar: 2020, p. 28).

The idea of imitation gradually became the basis for the thinking system in designing automatons. Baron Kempelen's Chess Playing (Mechanical) Turk and the Musician Lady automaton designed by the Swiss clockmaker Jaquet-Droz are known among the inventions of the eighteenth century. Vaucanson's Duck automaton, which simulates the nutrition and digestion processes in a way that can be observed from the outside, is another sample for the imitation of natural processes through automata (Riskin, 2003).

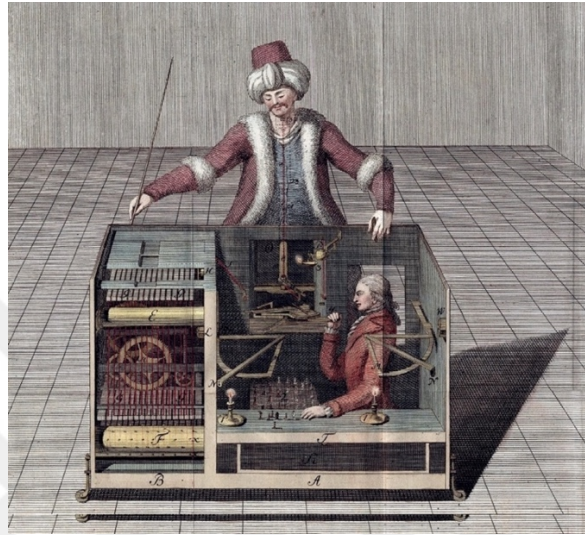


Figure 2.4 : Mechanical Turk, adapted from (Sunar, 2020, p.29).

In addition to the *Musician*, one of Jaquet-Droz's automatons, the inventions of the *Designer* and the *Writer* are exhibited at the Musée d'Art et d'Histoire of Neuchâtel in Switzerland. Vaucanson's three automatons including the *Duck* that was destroyed by a fire in the Krakow Museum in the 19th century, have all disappeared from the stage of history (Forster, 2016). Similarly, it is stated that the Mechanical Turk was destroyed in a fire in the 19th century (Andrews, 2016).



Figure 2.5 : The Musician, adapted from (Sunar, 2020, p.30).

The Romantic period literature following the Enlightenment was inspired by the idea of imitation such that scenarios that blur the boundaries between human and machine prevailed. In this period, unlike materialist Enlightenment philosophy, the fiction of human-like existences was based on malevolent supernatural creatures like monsters and vampires. Modern Prometheus *Victor Frankenstein* by the British author Mary Shelley written in the nineteenth century, the unfortunate story of Nathanael who fall in love with the android Olympia in the narrative of *The Sandman* by E.T.A. Hoffmann, and the Austrian writer Gustav Meyrink's novel called *The Golem* published in 1915 are all based on the ambiguity between living and inanimate, dream versus reality (Sunar, 2020). The story of Olympia was additionally adapted into an opera by Offenbach (Jackson, 2019).

While some of the imitation mechanisms were designed ingeniously, in other automaton designs dating from the late eighteenth to nineteenth centuries, technological limitations were circumvented through cheating in stimulating the living processes. Therefore, these inventions contained illusions. For example, the human chess player who was hidden inside the *Mechanical Turk* and the waste grain replenished completely independently of the nutrient pathway in the *Duck* automaton were using illusions. These tricks were based on the approaches around the limits of nature's imitability (Riskin, 2003).

The coexistence and convergence of science and art is observable in the development of these inventions which were occasionally based on illusions in an attempt of imitating life. Musical

performances of the eighteenth century appealed not only to the ear but also to the eye by using the power of expressing emotions. There was a tendency towards illuminating emotions through mechanical animation. While medical scientists had the tools to conduct research on the nervous and muscular systems that played a role in reflecting emotions, their contemporary inventors gained the ability to animate them artificially. Scientific research, creative design and artistic performances converged through these endeavors (Jackson, 2019).

The chess playing performances of Wolfgang von Kempelen's *Mechanical Turk* automaton was seen with interest by important figures of the time including Napoleon Bonaparte and Benjamin Franklin. Although being fraudulent in hiding a real person inside, this automaton was groundbreaking for later research and discovery (Fron and Korn, 2019). Von Kempelen's effort to create admiration for technology, albeit artificial, was remarkable (Sharkey and Sharkey, 2006). While previous automatons were focusing on mechanical imitation abilities of body movements, the *Mechanical Turk* pretended human attributed intelligence beyond that. Edgar Allan Poe met the *Mechanical Turk* in an exhibition. Based on his personal observations, Poe described in an article published in the first half of the nineteenth century in detail the functioning of the left arm that was used in playing chess. He stated that although the working mechanism of the automaton has not been determined yet, people with competence described it as a *pure machine* (Fron and Korn, 2019). Additionally, the left arm of von Kempelen's chess-playing automaton was sophisticated enough to inspire followed robotic arm designs. Kempelen, with the pantograph he designed, allowed the director to control the arm from inside the chest of the machine (Moran, 2007).

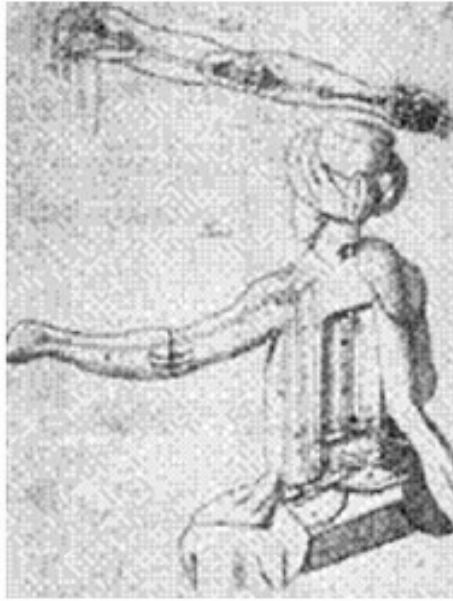


Figure 2.6 : Illustration of the left arm of Mechanical Turk, adapted from (Moran, 2007, p.106).

The illusion effect contained in artificial intelligence and robotics has continued being designed so skillfully that it could convince people that they are interacting with a machine that understands and feels them. In the early programs such as ELIZA (Weizenbaum 1966) and PARRY (Colby et al. 1971), various methods were deliberately employed to give the impression that they understood more than they did (Sharkey and Sharkey, 2006).

Early nineteenth-century Austrian scientist of mathematics and astronomy Joseph Faber attempted designing a mechanical speaking device inspired by von Kempelen's automaton. Just like the Mechanical Turk playing chess, this device simulated, with its bellows and vibrating reed system, the lung and larynx as the source of airflow and sound. This invention, which takes commands via keyboard, was innovative in terms of its rod mechanism used to control the sound system and making sound with the air flowing through the single tube-shaped structure like the living sample. Faber's invention that he named *Euphonia* was presented to the masses between 1841 and 1864 (Ramsay, 2019). A known model of the invention that has survived to the present does not exist (Url-1).

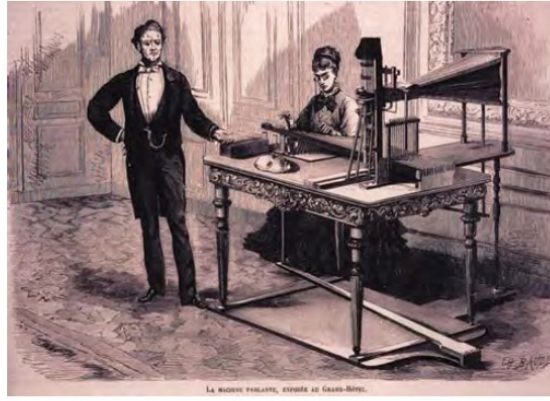


Figure 2.7 : Illustration of Faber's Euphonia being presented by his nephews at the Grand Hotel Paris in 1887, adapted from (Ramsay, 2019, p.16).

2.2.1.2 Advancing the mechanization of mind

Philosophers throughout the history hypothesized about the possibility of intelligent machines to understand the mechanisms of thought and intelligence, and eventually to explore what it meant to be a human. René Descartes held the idea of *mechanical man* as a metaphor than as a possibility. Gottfried Wilhelm Leibniz on the other hand believed in the potential of constructing logical rules based mechanical reasoning devices to solve disputes. Leibniz and Blaise Pascal designed calculating machines. These machines were mechanizing arithmetical calculations for humans, although Leibniz and Pascal did not promote their inventions as thinking devices (Buchanan, 2005).

Existing sources indicate that there is not sufficient technology-oriented research on nineteenth century automatons in place. It is argued that with the progress of the Industrial Revolution, the focus was shifted to groundbreaking technologies such as steam engines where on the other hand automatons became out of date. Although they were magnificent and impressive inventions, automatons' main purpose was to admire and entertain the masses. Historians who nominate the machine of the nineteenth century as the *engine* rather than automatons argue that the latter were built on more primitive technology and relied on external forces to trigger their movement. The inherent connection between automatons and large-scale industrial machinery is nevertheless undeniable. Charles Babbage, who is being considered among pioneering scientists in the computer history, attributed his motivation for his research on machine intelligence to his childhood interest in automata (Coll, 2014).

Babbage (1791-1871) was a mathematician and an inventor who worked on building machines capable of performing complex mathematical calculations. He designed the *Difference Engines* and the *Analytical Engine*. Although these machines were mechanical, they were pioneering to modern computer calculations that were implemented a century later based on logical design and architecture (Bromley, 1987). Babbage's machines were different with regards to previous automatons in the sense that they were designed to imitate the human mind rather than the body (Coll, 2014). Countess Ada Lovelace, whom Babbage worked with on the Analytical Engine projects, introduced the approach of separating the program from the hardware; that is, from the machine (Nahum, 2017).

At the beginning of the nineteenth century, Joseph-Marie Jacquard (1752-1834) designed the first programmable automatic textile production machine and managed controlling the patterns on the loom with punched cards. Each hole on these cards was recognized by the machine as either "open" or "closed" and the process operated like the "1" and "0" used digitally in modern computers (Baum and Freedman, 2017). Babbage used the punched cards of Jacquard for the first time in June 1836 and tried to develop user programs for his machine with them (Bromley, 1987).

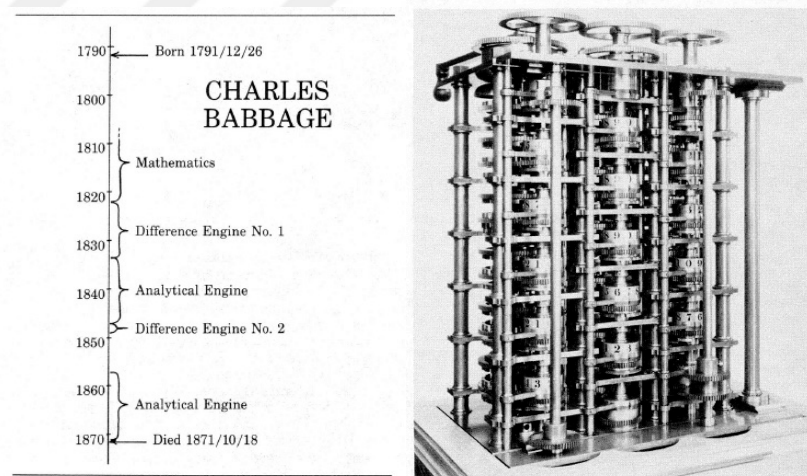


Figure 2.8 : Charles Babbage and his automatic calculating machines development line on the left, Difference Engine No.1 on the right, adapted from (Bromley, 1987, p.114 and 118).

Apart from his innovations in machines, Charles Babbage is acknowledged for having played a role in the development of the conceptual foundations of the British industry. In his book *On the Economy of Machinery and Manufactures* (1832), he defined an economic theory based on

systems consisting of rationalized and interdependent processes from a mechanical and mathematical perspective. He introduced a vision of an organized mechanical world which represented production systems in mechanized industrial factories (Coll, 2014).

The influence of the Industrial Revolution and the steam power are observable more apparently in the nineteenth century automatons. A steam-powered invention, *Steam Man*, looking like a man who is pulling a wheelbarrow was developed by Zadoc P. Dederick and Isaac Grass in 1868 and it was followed by automatons with similar technology such as the mechanical man invented by Canadian George Moore in 1893 that could take up to 8 km per hour (Baum and Freedman, 2017). The *Steam Man*, which, with no surviving examples recorded, is considered to have vanished from historical prominence (Url-2).

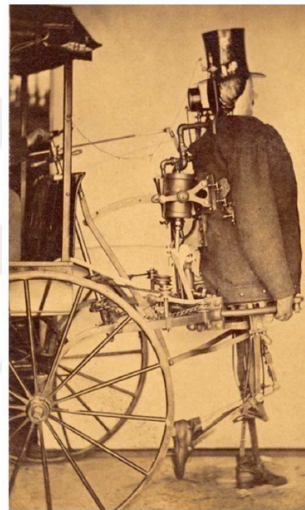


Figure 2.9 : Newark Steam Man, New Jersey by Isaac Grass and Zadoc Dederick, adapted from (Baum and Freedman, 2017, p.19).

At the end of the century, in 1898, the world met the potential of a remote-controlled device at the Electrical Exhibition organized at the Madison Square Garden in New York. At this fair, Nicola Tesla introduced his fully automatic remote-controlled underwater boat called *Teleautomata*. It is noted that the audience was not yet ready to adopt this technology at the time (Moran, 2007).

2.2.1.3 Emergence of the robot

While the theoretical concepts of robotics have roots in antiquity, their tangible realization necessitated the gradual development of foundational technologies throughout the twentieth

century. The mid-twentieth century marked a pivotal period, witnessing the rise of artificial intelligence and, concurrently, significant advancements in our understanding of human intelligence. This era's technological progress also facilitated the creation of the first robots as we recognize them today (Siciliano and Khatib, 2019).

During the first half of the twentieth century, the world welcomed the term *robot* that appeared in the 1920 play of the Czech playwright Karel Capek; the *Rossum's Universal Robots (R.U.R.)*. The root word *robota* is in Slavic and can be translated as *serving* in meaning. Isaac Asimov, the famous science fiction author, described the three laws of robotics to regulate interaction between robots and humans in his book *Runaround* in the 1940s (Siciliano and Khatib, 2019). It is assumed that Asimov first used the word *robotic* stemming from the word *robot* that later became a generic expression for all areas related to robot technology (Han, 2011).

The first known electromechanical robot was introduced with the contribution of the media and the public in the first half of the twentieth century. Roy James Wensley working at the Westinghouse Electronics designed a mechanism that reduced human labor to control electric auxiliary stations in 1927. Under normal circumstances, this operation was conducted by the controller calling the employee at the station. Wensley considered to accomplish this task with a series of circuit switches instead of human employees. The structure of the machine essentially consisted of two boxes of electronic mechanisms sitting on top of each other. However, the Westinghouse marketing team was aware about the "robot" concept announced by Capek at that time, and they managed to make it more mediatic by introducing the machine to the world embedded in a cartoon character like a body who grasped around the boxes. The structure was called *Televox* and is considered as an ancestor of the modern robot (Sharkey and Sharkey, 2006).



Figure 2.10 : Roy Wensley with the Televox, adapted from (Sharkey and Sharkey, 2006, p.16).

In 1935, *Alpha* was introduced to the public by its inventor, Professor Harry May, at the San Diego Fair. This robotic device could turn its eyes, open and close its mouth, sit and stand, and fire a gun. Westinghouse, the electronics giant of the time, attracted a lot of attention at the New York World's Fair in 1939 by introducing several mechanical man shaped machines. The machine that was called *Electro* among them could respond to commands in English while standing on a platform above the audience. Westinghouse developed eight robotic machines from 1931 to 1940 where they were all able to walk by moving their arms. These mechanical men, operated by very primitive loud boosters and vacuum tube circuits, were still not called "robots" at that time. This is because Capek's game and the word "robot" as a cultural notion had not yet become widespread enough (Moran, 2007).

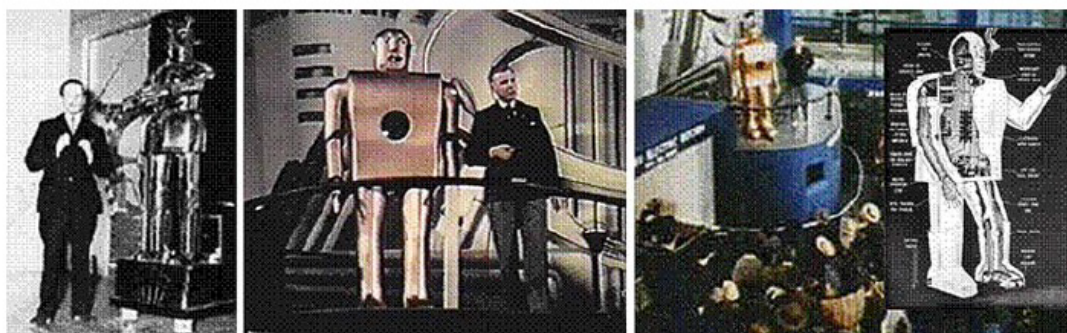


Figure 2.11 : Robotic machines at the New York World's Fair with Alpha to the left and Electro to the right, adapted from (Moran, 2007, p.107).

Apart from these, the patent for the first "position control device", one of the genetic inheritors of Kempelen's left arm of the Mechanical Turk invention, was received in 1938 by Willard Polard (Moran, 2007).

With the initial developments in cybernetics, computer science, and artificial intelligence in central period of the twentieth century, a new page was opened in the common adventure of machines and humans. While Alan Turing defended the futility of trying to embody a "thinking machine" in a human body, the physicality of robots was pushed to the background in the early years of artificial intelligence (Sharkey and Sharkey, 2006).

In 1948, Norbert Wiener introduced the ideas of interaction and feedback with the environment through sensors in his book *Cybernetics: or the Control and Communication in the Animal and the Machine*. In 1952, when Warren McCulloch moved his team to the MIT, comprehensive research in the field of cybernetics was initiated and the foundations of artificial intelligence and robotics were laid at the same time (Baum and Freedman, 2017).

Along with these developments, in the 1950s, Gray Walter designed a motorized robot turtle that could move towards the point light source it detected with its detectors in the dark room it was placed and could change direction according to the intensity of the light (Han, 2011).



Figure 2.12 : Walter's robot turtle, adapted from (Han: 2011, p.21).

Industrial developments accelerated the design of a programmable general-purpose robot by George Devol in 1954 and the first robotics company was founded by Devol and Joseph F. Engelberger in 1956 (Han, 2011). Until the 2000s, advances in the field of robotics fluctuated in various periods and extended into today.

2.2.2 Interdisciplinary foundations of the artificial intelligence

Artificial Intelligence is fundamentally interdisciplinary in nature. A comprehensive understanding of its historical development and contemporary status necessitates an examination of the reciprocal influences between scientific and societal domains.

The understanding of intelligence remains limited as the definitions and operational mechanisms of the mind, particularly within psychology (both behavioral and cognitive) and neuroscience, are still subjects of ongoing exploration. Among the disciplines influencing the evolution of artificial intelligence, physics is notable for rapid advancements. On the other hand, mathematics stands as the fundamental discipline underpinning AI. Furthermore, linguistics and communication theories are also highly relevant and can be evaluated in conjunction with mathematical developments.

This section examines the historical development of artificial intelligence in the context of the key disciplines that have shaped its development.

2.2.2.1 Emulating the human mind: The limits of psychology and brain studies

Modern psychology was formed in Europe towards the beginning of the twentieth century. The first experimental laboratory in the field was institutionalized in Germany in 1879 by Wilhelm Wundt. He is known to have explored introspective techniques alongside measures of reaction times and sensory processes. Later, Gestalt psychology was established by the Austria-Hungarian-born psychologist Max Wertheimer as a holistic approach to explain mental dynamics in 1912 in opposition to Wundt's existing atomistic methods. Sigmund Freud worked in the same period with focus on the unconscious aspects of mental life and argued that they were inaccessible to introspection. Behavioral studies replaced the study of inner mental life as the primary methodology in psychological research as the century progressed. John Watson manifested behaviorism in 1913 as a purely objective experimental branch of natural science with a goal of predicting and controlling behavior. The mind-machine metaphor began to flourish in the behaviorist school of psychology in the first half of the twentieth century (Penn, 2020).

Similarities between machines and human brain became a field of research for the scientists. Studies of psychology in collaboration with neurology resulted in the modeling of brain function and postulation about the significance of synaptic neuron action in learning. According

to Hiser and Francis (2000), “These models have been accepted in the artificial intelligence (AI) world as the basis for modelling silicon based (MOS) learning devices such as neural networks” (p. 122). Alan Turing was highlighting that digital computers are electrical, and the nervous system is also electrical since the early stages of AI (Turing, 1950). An analogy of human intelligence to electricity was proposed.

The emergence of cognitive science in the mid-twentieth century can be evaluated as a product of a time when the related fields of psychology, anthropology and linguistics were going through a transformation, and computer science and neuroscience were just coming into existence. Psychology, linguistics, and computer science were rather central, and the rest peripheral in the interdisciplinary activities contributing to the new field. It was in the central decades of the nineteenth century when components of the cortex were analyzed for understanding the human intelligence and identified as responsible for language processing. Brain was seen as the engine of reasoning by earlier philosophers, yet the modern revolution in psychology is admitted having started in the 1930s. Psychology was revolutionized as the science of behavior by the early to mid-twentieth century until it was recognized that mentalistic concepts were also needed to explain the behavioral data. Influenced by the scientific developments during the Second World War including in the information theory and the computer theory, the theories of mind flourished and a shift of paradigm occurred in psychology studies from behaviorism into cognitive research (Luger, 2023; Miller, 2003).

Behaviorism assumed that external responses to stimuli were key in understanding the human response system whereas cognitive scientists argued that the human system processed information while interacting with the rest of the world instead of giving a simple response to stimuli. It was the period when Norbert Wiener’s cybernetics was gaining interest, artificial intelligence was emerging as a separate concept when John McCarthy, Marvin Minsky, Claude Shannon, and Nathaniel Rochester held a conference on AI at Dartmouth College in 1956, Alan Newell and Herb Simon were experimenting with computer simulation of the cognitive processes, and Naom Chomsky was redefining theoretical linguistics thereby initiating a cognitive revolution in his *Syntactic Structures* of 1957. Chomsky argued on the generative grammar theory where internal representations were necessitated to describe human language. Although theoretical foundations were laid earlier, Christopher Longuet-Higgings is noted as the first scientist who used the term ‘cognitive science’ in 1973 (Luger, 2023; Miller, 2003).

The emergence of digital computer and design of its parts to enable computation triggered the construction of models for investigating human information processing at the same time. This approach to utilize concepts and tools of computation to understand human problem-solving issues was called *Information Processing Psychology*. Newell and Simon built the Logic Theorist (The Logic Theory Machine) and General Problem Solver to automate several theorems of Whitehead and Russell's Principia Mathematica of 1925. AI engineering was inspired by the human performance. McCulloch and Pitts at the MIT worked on demonstrating logic operations of human neurons whereas Donald Hebb conditional responses were based on the reinforcement of neural pathways (Luger, 2023).

The paper of 1943 with the title "A Logical Calculus of the Ideas Immanent in Nervous Activity" by the neurophysiologist Warren McCulloch and mathematician Walter Pitts is widely recognized for introducing the first computational model of a neural network (Url-4). McCulloch and Walter in 1943 introduced a computational theory by a logical model of neurons built on the cardinal assumptions of the theoretical neurophysiology of their time. Following physical assumptions were key to their model as stated in the *II. The Theory: Nets Without Circles* section of their paper:

1. The activity of the neuron is an "all-or-none" process.
2. A certain fixed number of synapses must be excited within the period of latent addition in order to excite a neuron at any time, and this number is independent of previous activity and position on the neuron.
3. The only significant delay within the nervous system is synaptic delay.
4. The activity of any inhibitory synapse absolutely prevents excitation of the neuron at that time.
5. The structure of the net does not change with time. (McCulloch and Pitts: 1943, p.4)

They utilized symbolism of "The Logical Syntax of Language" of R. Carnap published in 1938 and referred to the "Principia Mathematica" of 1925 by B. Russell and A. N. Whitehead to draw notations to enhance the symbolic language. They also explicitly referred to "Grundzüge der Theoretischen Logik" by D. Hilbert and W. Ackermann of 1927, while presenting their neuron theory.

Marvin Minsky, in his article “The Society of Mind”, emphasized that the emergence of computer science was opening research areas not only in the computational matters but also in the understanding of human thought while introducing a new theory of psychology (Minsky, 1987). The theory assumed that the human mind comprises multiple agencies which eventually constitute a large and complex “society of mind”. This conceptualization drew an analogy to the biological body, where organs, cells, and chemical processes collaborate and communicate to constitute a unified, functional system. Minsky (1987, p.22) argued that “Minds are simply what brains do”. Although minds are abstract, they can be understood as a process that guide our brains through various states. The changes in states of minds are detached from the physical nature of the states. This principle extends to computational systems according to Minsky, where the functionality of a computer can be assessed without a detailed understanding of its individual physical components. In alignment to that, Minsky (1987) argued that “...brains use processes that change them-selves. This makes it impossible to separate those processes from what they produce” and added that “The study of processes that change themselves is relatively new to science, and started to evolve only with the invention of computers” (p. 23). *The Society of Mind* also questioned the concept of consciousness and the eligibility of a computer for being “sentient, conscious, self-willed, or in any other way aware of itself” (Minsky:1987, p.26). It would be contradictory to speak of absolute human self-awareness given that the knowledge about what is happening inside of our minds during the state transitions remains limited. Minsky claimed that human mind relies on transient short-term memories to access recent thoughts. The content of those memories is changed during the process of contemporary reflection. Any attempt to introspectively examine one's mental state invariably alters that state, constraining the human consciousness about its own functioning. Introspection consequently does not suffice in understanding human consciousness. On the contrary, it is proposed that machines could be constructed to record state changes of “mind” better than that is allowed by the nature of the human mind. In this regard, machines might have better capacity to become aware and conscious about how they work than the human mind.

Minsky (1987) introduced another issue related to the mind-body problem: “The Immanence Illusion: Whenever you can answer a question without a noticeable delay, it seems as though that answer were already active in your mind.” (p.30). Our thoughts appear to be directly linked with the physical world however much of what we perceive is largely illusory. Our

appreciations of the objects in the world usually stem from the stored-up memories rather than directly from the outside world. Minsky explained this by the example of an object appearing to one's eyes, where the vision agents start picking up memories before one can actually perceive the physical world. Accordingly, one cannot distinguish between what is observed and recollected from stored appearance. Eventually, it is concluded that there is no absolute, single, objective world of thought; instead, every mind constructs its individual internal universe.

Minsky's theories proposed in the late 1980s illustrates the continuation of the interdisciplinary research of brain studies and AI initiated earlier in the twentieth century.

2.2.2.2 Impact of developments in physics as a science

Artificial Intelligence as a science was established based on the formalization efforts in science; especially mathematics starting from the seventeenth century. The developments in physics further contributed to the intellectual foundations of AI and together with the progress in engineering enabled its realization, in other words made it possible for the intelligent machine to go "live". Twentieth century physics influenced the development of artificial intelligence by the introduction of foundational texts and theories in the first half of the century, in addition to impacting its physical enablement and deployment according to hardware limitations and possibilities of the time.

The theories of thermodynamics contributed to the foundations of intelligent machines. Erwin Schrödinger (1887 to 1961), widely acknowledged as the father of quantum mechanics, published "What is Life? The Physical Aspect of the Living Cell" and proposed that life would depend on negative entropy to survive. Shortly after, in 1948, Norbert Wiener (1894 to 1964), the father of cybernetics, introduced a new field of control and communication within and between living organisms, machines, and organizations. Meanwhile, Alan Turing (1912 to 1954), pioneering scientist in artificial intelligence, proposed the Turing Machine model and a strict mathematical definition of computing in his 1936 article of "On Computable Numbers, with an Application to the Entscheidungsproblem" and followed with the "Computing Machinery and Intelligence" in 1950 introducing the Turing Test to demonstrate the intelligence of a machine. Wiener's book, "The Human Use of Human Beings: Cybernetics and Society" was published in 1950 as well and provided a basis to the idea that the intelligence of humans and machines could be realized through interactive cognition (Li, 2023). Schrödinger's

and Wiener's approaches together with Turing's pioneering queries about thinking machines converged into the statement that "control is the use of negative feedback to reduce entropy and ensure the stability of the embodied behavioral intelligence of a machine" (Li: 2023, p.2). The concept of entropy as defined in statistical mechanics moreover was one of the cornerstones of the Information Theory proposed by Claude Shannon. In his article "A Mathematical Theory of Communication" submitted in 1948, Shannon aimed to define a general theory of communication. His work influenced theories of information, ultimately data, and the artificial intelligence concepts that relied on it (Shannon, 1948).

Science has been using class of systems while constructing its theories. Classical physics followed the approach that systems could be described by systems of differential equations and applied that while working on a theoretical definition of certain phenomenon. Mathematical psychology in the 1950s and 1960s acknowledged Markov processes as the class of systems to theories of phenomena. While seeking for a description of intelligent systems, physical science and engineering used continuous variables as the underlying state descriptions. Researchers in the field of cybernetics and engineers who were concerned with pattern recognition continued using continuous variables whereas researchers in the field of artificial intelligence used the programming system itself to describe intelligent systems based on a class of symbolic systems. That means, they utilized a system of symbols and data structures (Newell, 1983). Symbolism assumed cognition as computation in the form of processing of symbols, where human thinking could be described by symbols. According to this view, an information processing system for solving general problems could be formulized using mathematical methods and materialized into a physical symbol system with a rule-based memory to obtain, search for, and control knowledge and operators (Li and Du, 2017).

The uncertainty view introduced in physics, in particular quantum mechanics, influenced shift in artificial intelligence approaches from deterministic to more probabilistic models. Newton's theory proposed a deterministic world view where nature acted according to definite, harmonious, and orderly rules whereupon future events could be determined. Quantum mechanics suggested on the other hand uncertainty principle as an essential attribute of nature as introduced by the German physicist Werner Heisenberg. Not only the objective world but its mapping into in the human mind as a subjective world, in other words the human cognitive process, contained uncertainty. Abstraction, imagination, and randomness are key features of

human thinking relating to intuition, association, analogy, and creation that could range in an indefinite number of patterns. The acceptance of uncertainty in the outside environment as well as in the human cognition introduced new perspective in research on artificial intelligence with uncertainty (Li and Du, 2017).

An analogy of intelligence to electricity is proposed in the intersection of physics with artificial intelligence while referring to network and circuits in brain modeling. The brain theory that emerged in the early twentieth century proposed the view that neural networks were heterogeneous systems of neurons. The concept relating to the electrical firing of neurons and the "synapse" was introduced. Warren McCulloch and Walter Pitts during the 1940s formulated a mathematical theory that described the behavior of neurons as Boolean units by means of a logical element which would switch to "on" and "off" state depending on whether the afferent spikes would excite a neuron. This theory assumed that information was transmitted by action potentials between the neurons where only a firing neuron was able to communicate with other nerve cells. The physiologist Donald Hebb introduced the concept of "neural assembly" as a group of cooperating densely connected neurons and worked on understanding the dynamics of neural networks. During the "golden decade of cybernetics" between 1955 and 1965, various models of neural networks were introduced. Frank Rosenblatt designed a layered network and introduced 'perceptron' with the limitations later proven by Minsky and Papert (Buhmann et al., 1986). The faith in human thinking and intelligence could be implemented based on cooperating neural models with the help of fast computers, in other words the implementation of AI on neuronal basis, decreased eventually according to Buhmann et al. (1986) and transformed into a more abstract, algorithmic approach.

Artificial intelligence algorithms have been inspired by the concepts of thermodynamics. Sargent (2025) explains this connection:

Eighteenth and nineteenth century, Euler, Lagrange, and Hamilton extended and perfected ways to use calculus to optimize weighted sums (integrals) of functions of quantities over time. That put in place building blocks for a twentieth first-century Hamiltonian Monte Carlo simulation technique that powers modern Bayesian estimation and machine learning. In the nineteenth century, Clausius, Maxwell, Boltzmann, and Gibbs created ways to describe thermodynamics statistically. They discovered a second law of thermodynamics cast in terms of entropy, an expected value

of the logarithm of the ratio of one probability distribution to another. One of those probability distributions is a flat uniform distribution that statistically represents complete disorder, the other a distribution that represents “order” in a particular statistical way. Many machine learning algorithms use entropy to measure discrepancies between possible models’ probability distributions and an empirical distribution traced out by data.”. (p. 6)

Advances in physics influenced the construction of computing machinery and the underlying infrastructure for artificial intelligence. The architectural changes and hardware implementations of the intelligent machines within the limits of physics and engineering vice versa had an impact on the development of intelligence theories with intelligence being considered as a form of information processing. Charles Babbage, a mathematician of the nineteenth century is acknowledged as one of the first AI implementors with his design of the first known programmable mechanical computing machine. His special purpose computing machine, the *Difference Engine*, was followed by the invention of the general-purpose programmable computing machine, the *Analytical Engine*, that could yet not be constructed during his lifetime. This engine mirrored modern computer design by the division of the store (memory) and the processor (mill), and in that sense was resembling a digital machine that could be programmed by a set of operations coded on punched cards. However, it took until the central periods of the twentieth century when digital computers achieved sufficient memory and processing power to implement intelligent programs (Luger, 2023).

The first large computer was constructed using vacuum tubes in the 1950s. The invention of the transistor was a turning point in the history of the computers and was followed by further developments such as the integrated circuit. The journey supported by physics continues with various alternative research including in the fields of quantum computing and nanotechnology (O'Regan, 2021).

2.2.2.3 Mathematical foundations of artificial intelligence

Mathematical foundations of artificial intelligence are considered together with the development of logic such that it can be claimed that their origins in the history date back to the philosophy of Aristotle (Luger 2002; Luger 2023). The study of nature was equivalent to the study of things that change for the philosopher who distinguished between matter and form.

Change occurred when matter transitioned into a new form. Aristotle's matter and form distinction contributed to modern computer science notions like symbolic computing and data abstraction. Namely, forms of electronic material are manipulated and changed as part of the solution process in computing. Aristotle discussed the science of knowing in his *Logic* where it was analyzed whether certain propositions can be concluded as "true" from other related propositions that are known as "true". In that sense, he was referring to syllogism using modus ponens as deductive form. Axiomatization of reasoning was further developed much later by the studies of Gottlob Frege, Bertrand Russell, Kurt Gödel, Alan Turing, and Alfred Tarski amongst others.

First, Gottfried Willhelm von Leibniz introduced a system of formal logic after Aristotle in his "Calculus Philosophicus" along with a machine automating the steps of calculation. Leonhard Euler in the eighteenth century found a way of abstractly capturing and representing structure of relationships while he was studying the connection of the riverbanks and islands of the city of Königsberg by the bridges. The graph theory emerged thereby that is an essential formalization used by AI problem solving by representing the space of a problem with the possible solutions in terms of the state space graph and defining search strategies through the paths towards a solution. Charles Babbage, the nineteenth century mathematician, was also occupied with the goal of automating arithmetic calculations and liberating humanity from them while designing a general purpose programmable mechanical computing machine, that became the ancestor of modern computer. The Analytical Engine was designed based on separation of memory and processor where algebraic relationships were implemented and mechanically manipulated independent of the values passing through the mill of the calculating machine. This reflected the abstraction and manipulation of form after Aristotle. George Boole, another nineteenth century mathematician, worked on the formalization of the laws of logic and innovated the basis for binary arithmetic. Boolean algebra only used the two numbers "0" and "1" and mainly three operations "AND", "OR" and "NOT". This system was simple yet powerful enough to capture full power of logic and form the basis of modern efforts to formalize logic. Boole defined his main motivation in all these efforts as to investigate operations of reasoning in human mind by describing them in symbolic language of Calculus. The attempt to formalize and establish the science of logic was eventually to understand the nature and structure of human mind. Gottlob Frege built a mathematical specification language in his

“Foundations of Arithmetic” that rectified contemporary efforts of his time in formalizing logic. The formal language that was introduced by Frege is now called “first-order predicate calculus”. This language established a basis for representing knowledge and automating reasoning in artificial intelligence systems. Alfred North Whitehead and Bertrand Russell aimed defining entire mathematics through formal operations based on a collection of axioms and theorems represented as strings of characters. Accordingly, proofs would follow by applying well-defined rules on these strings. Whitehead and Russell’s purely formal approach to mathematical reasoning provided a strong basis for automated theorem-proving and hence theoretical foundation for artificial intelligence. Alfred Tarski was another scientist who contributed to the theories of formal semantics in the early twentieth century. He introduced a theory of reference and truth-value relationships that was referred by other scientists in studies of programming languages (Luger, 2002).

In addition to the development of formal systems, the probability theory, concept of randomness and paradigm shifts leading to the incompleteness of mathematics is important to analyze while investigating conceptual foundations of artificial intelligence.

The concept of probability has long been established in human thought based on random events in life, but it emerged as a mathematical theory in the middle of the seventeenth century. It is claimed that the birth of Probability Theory was triggered by the ambition of a noble French man named Chevalier de Méré to increase his fortune by gambling. While changing the rules of the dice game he was playing, he consulted his friend Blaise Pascal (1623-1662), one of the best mathematicians of that period, about the results that he observed. Pascal together with his contemporary Pierre de Fermat, with whom he was exchanging ideas by correspondence, created the roots of Probability Theory, which became an important branch of mathematics (Karaçay, 2006).

Probability can be seen as the measure of uncertainty; it represents randomness. Statistics use it to define events that are unbiased and uncorrelated where statistical randomness was later addressed by the information entropy concepts in the information theory. From a philosophical perspective, uncertainty is distinguished between two separate types where in the first type of uncertainty, that is called the *aleatoric probability*, the occurrence of the event is completely random, unpredictable. On the other hand, the second type of uncertainty stems from our lack of knowledge about the event which is defined as the *epistemic probability*. Important steps

have been taken for the formulation of probability since the early twentieth century, when mathematics began to be built based on axioms; largely based on set theory introduced by Georg Cantor (Karaçay, 2006).

In 1960, Ray Solomonoff suggested the concept of algorithmic probability and five years later, unaware of his work and each other, Andrey Nikolaevich Kolmogorov, and Gregory J. Chaitin introduced the same concept of algorithmic randomness. Accordingly, “A sequence that cannot be written with a shorter algorithm than itself is random.” (Karaçay:2006, p.14). Following example illustrates these concepts where the transferring of two different messages are represented by a sequence of binary digits 0 and 1:

010101010101010101 (1)

01101100110111100010 (2) (Karaçay: 2006, p.10)

In the initial message (1), since there is a certain pattern that can be “coded” by an “algorithm”, the message length to be transferred can be shorten in string length. Instead of writing the entire message 010101010101010101 (1), the algorithm “write 01 ten times” can be inserted into the computer. On the other hand, for the second message (2), a shorter algorithm than the full sequence is not available. The available algorithm would have to include “write 01101100110111100010 (2)”. Hence, the latter is called a random sequence (Karaçay, 2006).

Scientific theorems are based on observation and experiments where the outcomes are not just a summary of raw data, but their meaningful interpretation that can be applied in forecasting future projections as well. There exists at least an algorithm to transmit a message sequence which is the sequence itself. There might be additional algorithms to transmit the same sequence. If an algorithm is not shorter than the length of the message sequence itself, it cannot be a theory. If it is shorter and able to forecast about upcoming sequences as well, this algorithm is a theory. The simplest among multiple existing theories should be preferred which means the shortest algorithm in terms of bit length. This choice is referred to as Occam’s razor as explained in Karaçay (2006).

In 1900, at the second International Congress of Mathematicians, David Hilbert (1862-1943) held a lecture on Mathematical Problems where he introduced twenty-three questions and requested clarification for them. These questions became of great influence not only in the development of mathematics in the twentieth century, but also opened the path to the concepts

of machine computation. At the beginning of the century, mathematicians were looking for a way to define what makes a proof valid and they investigated mathematical foundations in this purpose which resulted in the different approaches of logicism, intuitionism and formalism. Bertrand Russell and Alfred North Whitehead claimed that all math could be reduced to logic in their “Principia Mathematica”. Luitzen Egbertus Jan Brouwer (1881-1966) initiated intuitionism that aimed to construct mathematics intuitively and rejected both Cantor’s set theory as well as Russell’s rationalism. In 1920s, David Hilbert was working on establishing a formal mathematical language that was eventually called the *Proof Theory*. This language was proposed as a formal system based on an alphabet with a well-defined grammar, a finite number of axioms and rules (Karaçay, 2006).

According to the essence of the Hilbert’s formalized system, mathematics must have had the following properties:

- (i) The system should be consistent. In other words, contradictions should not be derived from axioms.
- (ii) The system must be complete. That is, every proposition (or the opposite) given in the formal language of the system must be deduced from the axioms.
- (iii) The truth value of each proposition within the system (that is, whether it can be deduced from the axioms or not) should be decided algorithmically. (as quoted in Hazar, 2022, p. 117)

Mathematics as a formal system should be consistent, complete, and decidable. Consistency ensures that a proposition cannot be both valid and invalid at the same time. Completeness on the other hand requires every proposition p of the system to be proved as either to be valid or invalid. Decidability can be ensured by a mechanical method that allows to determine in finite steps whether an expression created in a formal system can be proven or not, that is, whether it is a theorem. Hilbert was looking for a mechanical method, in other words an algorithm, to test the validity of a proof independent of human intuition or intelligence (Karaçay, 2006; Kayaönü, 2000).

The book “Principles of Mathematical Logic” that was published in 1928 by Hilbert and his student Wilhelm Ackermann was based on Hilbert's logic lectures from the 1900s (Hazar,

2022). Hilbert's decision problem (*Entscheidungsproblem*) that was covered in the published book, influenced the introduction of universal machine concepts by Alan Turing in 1936.

David Hilbert's mathematics as a formal system was critically challenged by Kurt Gödel (1906-1978) by the incompleteness theorems. At the beginning of his article "On Formally Undecidable Propositions of Principia Mathematica and Related Systems", Gödel highlighted that mathematics had developed in the direction of greater precision which eventually led to wider range of formalization. It was reasonably assumed that the most comprehensive formal systems of the time, namely the Principia Mathematica and the Zermelo-Fraenke's axiom system of the set theory, were sufficient to formalize all existing proof methods used in mathematics by reducing them into a few axioms and rules of inference that could eventually decide on every mathematical question that was formalized in the system. Gödel examined this assumption and showed that there exist questions whose answer could not be decided as part of the formal systems of mathematics, in other words, there exist valid proposals in a formal system whose validity cannot be proved (Gödel, 1931).

To show that Hilbert's decision problem cannot have a solution, Alan Turing took a step further and explored the possibility of inventing single machine, the *universal computing machine*, demonstrating the ability to compute any computable sequence. The conceptual universal machine as introduced by Turing (1936) was referred as the *Turing Machine* later by his Ph.D. supervisor Alonzo Church (Hazar, 2022). Turing defined computable numbers as those whose decimals are calculable with finite means in an analogy to the human memory that is assumed as being limited too. He introduced the concept of configuration of an *automatic machine* which completely determines its possible behavior or the stage of motion. He argued that if there is a general process for determining whether a formula of the Hilbert function calculus is provable, then the determination could be carried out by a machine (Turing:1936, p.249).

In Turing (1936), Alan Turing explicitly highlighted that what he shall prove would be quite different from Gödel's proof that had shown that there are propositions such that neither validity nor invalidity is provable; in other words, consistency of the formal system cannot be given. Turing using his conceptual universal machine, different than Gödel, showed that there was no general method to tell whether a given formula is provable within the range of functional calculus, therefore that mathematics was undecidable. Additionally, in the *Mathematical Objection* section of his "Computing Machinery and Intelligence" article, Turing explains

Gödel's incompleteness theory and adds that it "...shows that in any sufficiently powerful logical system statements can be formulated which can neither be proved nor disproved within the system, unless possibly the system itself is inconsistent." (Turing:1950, p.444). Accordingly, there exists problems that cannot be solved as well as logical propositions that cannot be decided by machine computing just like they cannot through the human thinking. It is argued that this statement brings the concepts of human and machine intelligence closer together, suggesting that they are becoming more comparable (Sarı , 2021).

Proving a proposition within a formal system means being able to validate it by following the axioms and rules of inference (arithmetic rules) of that system. Alan Turing theoretically showed that there exists an algorithm (computer program) that performs every computable operation within a logical system. This algorithm or computer program is called the *universal machine*, or the Turing Machine. Accordingly, the validity of a proposition p within a formal system should be demonstrated by the existence of a Turing Machine that performs that job; in other words, proving by means of the execution of mechanical processes. Turing Machine can be used to prove Gödel's incompleteness theorem in a more general way that is demonstrated as per following example provided in Karaçay (2006).

According to the example, there exists a machine called Universal Turing Machine (hereafter UTM) that can provide a valid answer to every single question asked by a human. UTM is not necessarily a physical machine, but a computer program based on an algorithm that can prove every valid proposal within a formal system. UTM is questioned on behalf of Gödel and will produce an answer based on an algorithm that will eventually be a subfunction of UTM's main algorithm. The answer will be represented by $P(UTM)$.

The question G , namely the proposal that is asked to UTM to prove is formulated as follows:

G : "UTM never says G is true" (*)

The (*) is used to distinguish the proposal G from the G used within the question sentence that are identical. If UTM is asked whether G is valid and the answer is yes, then G (*) becomes invalid and vice versa which is inherently conflicting.

This example indicates that "There are valid propositions in every formal system that cannot be proven". Chaitin integrated this result into probability theory by suggesting that "There are random numbers whose randomness cannot be proven." (Karaçay:2006, p.21).

2.2.2.4 Philosophical background and introduction to linguistics context

What began as a revolution in astronomy and cosmology in the writings of Copernicus, Tycho Brahe, and Kepler extended to physics and metaphysics in the works of Galileo, Descartes, and Gassendi. In search of a new physics compatible with Copernican cosmology, these philosophers attempted to explain the structure and motions of the earth in quantitative terms that were increasingly proving successful in describing the sky. Mechanistic philosophers, who completely broke away from Aristotle's qualitative physics, which ultimately explained physical phenomena with non-material 'substantial forms', sought to explain terrestrial and celestial physics only with the geometric properties of moving objects. (as quoted in Hazar, 2022, p. 20)

The scientific revolution from the Renaissance to the Enlightenment and the mechanical view of nature that developed with it affected different geographies in different ways. While the intellectual revolution in Western Europe was based on induction, experiment, and observation, in Central Europe it resulted in mathematical thinking and thus the deductive method (Hazar, 2022).

Questions about how we know, how and where from we understand what we know, how to prove the truth of what we know, and what the starting point of our method is or could be when explaining what we know to the other party with words, have now turned into fundamental questions, especially in the footsteps of René Descartes (1596-1650), who can be considered the intellectual turning point of the modern age, and Francis Bacon (1561-1626), who greatly influenced the philosophers of the modern age. (Hazar: 2022, p. 21)

Descartes suggested a direct relationship between language and thought and considered the ability to use speech and symbols to exchange thoughts with others as a distinguishable criterion of humans from machines within the framework of Cartesian philosophy. Moreover, the observation that machines could outperform humans in specific tasks while failing in others suggested their actions were limited by their designed configurations. Humans, conversely, operate based on the knowledge acquired through their minds (Özcan, 2022).

Descartes influenced the French Port Royal School of the seventeenth century which followed the Platonic and Augustinian tradition originating from the Port Royal Monastery. The school viewed words as the form of expression of thoughts and feelings existing in the human mind like Descartes' view of words or speech as a form of transmission of human emotions and thoughts. They acknowledged ideas, rather than images or sensation, as the source of words and eventually the source of languages. Later during nineteenth century, Wilhelm von Humboldt followed Descartes' view that language was the most fundamental and distinguishing ability of humans and moreover believed that there existed principles that all languages commonly based on within the framework of the Port Royal School's understanding of language based on reason. Humboldt's thought of creating forms common to all existing languages contributed to Noam Chomsky's theory of universal grammar. Chomsky is recognized as a pioneer in the mathematical analysis and the biological study of language. According to Chomsky, there existed a language-specific biological "language ability" module in our brain that makes language an innate human ability where the human mind can produce unlimited sentences with limited rules due to its structure. Chomsky, while establishing direct connection between the human mind and the language ability, developed the theory of universal grammar as a productive system within a theoretical framework. He anticipated that the biological language module had a "computational" order and mathematical functioning. The recursion and merging feature of human language unit worked basically based on combining two elements to create a new element. The "processor" in the brain combined sounds and meanings, thereby producing an unlimited number of meanings with a limited number of elements. Chomsky examined the formal structures of language and put forward the theory of transformational grammar in 1957 (Özcan, 2022).

There are aspects of Chomsky's theory of universal grammar that continue to be open to debate or criticism today. It has not yet been proven whether humans are born with a biological module specific to language. Nevertheless, Chomsky directly influenced the establishment of new dimensions of research in the field of language from biology to mathematics. He questioned the requirements of an automated system that would operate by rules and realize the generative grammar of a natural language. Consequently, Chomsky contributed to artificial intelligence studies and inspired machine translation applications (Kerimoğlu, 2021; Özcan, 2022).

Gottfried Wilhelm Leibniz (1646-1716) was influenced by Descartes' philosophy as well, especially the mathematical mechanism, and the paradigm changes of the modern age. Leibniz has a strong place in the history of symbolic logic, yet his treatises in the context of the subject were not published while he was living, and innovations had to be rediscovered by scientists of later centuries. The domain became a subject of study in two separate fields in mid- nineteenth century, namely "logic as calculus" and "logic as language" (Hazar, 2022).

Leibniz had a dream to create a "universal language"; a rational formal language that goes beyond natural languages, that would allow individuals without confusion of meaning to reach true practical and theoretical knowledge. There was serious work in the seventeenth century on formal language structures. *Steganography*, for example, was used to encrypt messages and decipher messages in an unknown language, whereas polygraphs were intended as a universal communication tool with the help of the characteristics and the dictionary of terms they contained that could be used by individuals of different natural languages. These types of formal languages are in general classified as *pasigraphy* and are considered in the group of a priori languages, because they are invented with specially designed arbitrary characteristics. Leibniz's characteristic language, *characteristica universalis*, was a priori philosophical language, and pioneering in the approach that each concept could be given its own characteristic number. This was meant to be the logical connection of scientific facts by which even the hierarchical order of the sciences could be determined. The new logic that Leibniz aimed to achieve through *arithmetic calculus* (calculus ratiocinator) as a calculation procedure between characteristic numbers, would provide content-free justification for his universal language (Hazar, 2022).

Leibniz was inspired from the Jesuit missionaries from China by the pasigraphic language structure of Chinese as well as the Chinese mysticism of existence and nothingness which he could correlate to his own metaphysics and demonstrate the connection between God and things that come into being. The existence and nothingness philosophy were directed to the binary number system (1,0) that he mathematized on metaphysical foundations (Hazar, 2022).

In his short treatise "Explanation of Binary Arithmetic", Leibniz explains:

...by 0 and 1 is found to contain the mystery of the lines of an ancient King and philosopher named Fuxi, who is believed to have lived more than 4000 years ago, and whom the Chinese regard as the founder of their empire and their sciences. There are

several linear figures attributed to him, all of which come back to this arithmetic, but it is sufficient to give here the Figure of the Eight Cova, as it is called, which is said to be fundamental, and to join to them the explanation which is obvious, provided that one notices, firstly, that a whole line — means unity, or 1, and secondly, that a broken line -- means zero, or 0. (Leibniz:1703, p. 226)

	000	0	0
	001	1	1
	010	10	2
	011	11	3
	100	100	4
	101	101	5
	110	110	6
	111	111	7

Figure 2.13 : Binary interpretation of lines of Figure of Eight Cova adapted from (Leibniz:1703, p. 226).

Since Leibniz did not publish the treatises he wrote in the context of the subject, the innovations in the field of logic delayed until mid-nineteenth century. Symbolic logic became than serious subject of study in separate fields of "logic as calculus" and "logic as language". George Boole (1815-1864), unaware of Leibniz's work, introduced algebraic logic that was transformed by Ernst Schröder (1841-1902) into Boolean algebra who was aware of Leibniz's universal language. Boolean algebra represented a limited universe of calculus ratiocinator; the new logic that Leibniz was trying to achieve through arithmetic and fell into the field of "logic as calculus". Leibniz was aiming to represent thoughts in a calculable manner to enable measuring the validity of arguments. Friedrich Ludwig Gottlob Frege (1848-1925) on the other hand, aware of Leibniz's universal language studies, created the first-level predicate logic in the appearance of a *lingua characteristica* (characteristica universalis) with its syntactic structure and represented the field of "logic as language". Leibniz's dream of a universal language was further reflected in the attempts of defining formal language of mathematics in the early twentieth century. David Hilbert was moreover asking for evidence that mathematics was complete, consistent, and that the validity of an argument could be decided by an algorithm within the formal language of mathematics. Eventually, this decision problem was falsified as

explained in the previous sections which eventually implied the failure of Leibniz's dream of a universal language. Turing's response to Hilbert's decision problem, Turing (1936), introduced an algorithm in such well-defined steps that even a machine instead of a human being would achieve the same result by following them. These developments opened a new path to human-machine (computer) interactions with further studies in defining instructions for computers and communicating by means of compilers, interpreters and eventually by the design of programming languages (Hazar, 2022).

2.2.3 History of AI as part of the computer history narrative

The historical progression of artificial intelligence is closely linked with the evolution of computers. By the mid phase of the twentieth century, important publications and technological inventions were contributing to the foundations of the Information Revolution:

The first edition of Norbert Wiener's book, *Cybernetics, or Control and Communication in the Animal and the Machine*, was published in 1948. Interestingly enough, so was Claude Shannon's seminal paper, "A Mathematical Theory of Communication." William Shockley's paper on the transistor followed in 1949. These texts, combined with Alan Turing's "On Computable Numbers, with an Application to the Entscheidungsproblem" (1937) and the work of John von Neumann (e.g., his 1958 book, *The Computer and the Brain*), comprise the foundations of the Information Revolution, with the invention of the transistor forming the technological foundation of this revolution. (Wiener:2019, p.23)

During the Second World War, cybernetics and computer technology cooperated for the first time. This was as part of research for an anti-aircraft technology in the United States. In addition to Norbert Wiener's proposed solution to control of information processes, Claude Shannon's mathematical theory of communication fostered research in prediction of flight paths in fire control systems. Cryptography was another application area of computing systems during that time. The German Enigma code was eventually deciphered using computer aided cryptography. Probability theory, that depends on possibilities and corresponding statistic frequency of previous occurrences to calculate predictions of a system, was at the heart of research and application of mathematics in these new fields (Dreher, 2020).

Norbert Wiener explained in 1956 the motivation to his proposed solution of the control problem as quoted in Dreher (2020, p.18):

.... in order to obtain as complete a mathematical treatment as possible of the over-all control problem, it is necessary to assimilate the different parts of the system to a single basis, either human or mechanical. Since our understanding of the mechanical elements of gun pointing appeared to us to be far ahead of our psychological understanding, we chose to try to find a mechanical analogue of the gun pointer and the airplane pilot.

The calculators in Wiener's anti-aircraft systems were computers that were able to process data on a moving target as input and calculate the navigation of bullet to the target as the output. Erroneous targets were eliminated from the output via negative feedback as filters and consequently the flight path was constantly being improved with the help of updated tracking data. The feedback system was essential to the overall control system. Meanwhile, Claude Shannon was experimenting with stochastics; utilizing probabilities and statistics of frequencies in calculations, to construct the English language by approximation according to everyday usage. Statistics provided information about previous occurrence frequencies and probabilities about patterns of combinations of elements. Based on these, future estimations could be calculated. This process resembled cryptographic procedures (Dreher, 2020).

The term 'information' related to a technical system's transmission capacity both for Shannon and Wiener. This approach was based on statistical thermodynamics rather than being concerned with the semantic meaning information. Accordingly, information was defined based on the probable distribution of physical elements in a closed system with their tendency to *entropy*, that means "disorder", or "mixture". Its opposing concept is *negentropy* which describes "segregation", or "demixing". Cybernetics' theory of information was based on negentropy. The calculation machines differentiated between the two values "0" and "1" to keep the negentropy representing information and measured alternative between two values as a bit (Dreher, 2020).

According to the joint conference paper about *The History of Artificial Intelligence* of the year 1977, AI began its transformation from a science and a fantasy idea into reality in the early to mid-1950s, and this was made possible by the anticipation that the computer was the most

promising tool to realize humankind's ancient dream of creating human-made intelligence (McCorduck et al., 1977).

The first computers that fit to today's description were developed during this period. Research by wartime scientists seeking ways to produce faster solutions to practical problems led to the development of digital computers to experiment with fast computational methods. Initially, computers were huge in size made of several thousand vacuum tubes and were operating slow and unreliable (O'Regan, 2021). The remainder of this section offers a concise historical overview of computers, with references primarily drawn from O'Regan (2021), unless otherwise specified.

Konrad Zuse, a civil engineer born in 1910, was researching in Germany on automatic calculating machines isolated from the developments occurring elsewhere in the world. After graduation from the Technical University of Berlin, he worked for the airline manufacturer Henschel for a while and established his own company where he would launch the Z1 machine in 1936 that remained operational until 1938. Z1 was a *binary electrically driven mechanical calculator with limited programmability* supported with the metallic shafts that could shift from position 0 to 1 and vice versa. During the years of the Second World War, Henschel helped Zuse obtain exemption from the army because he was needed as an engineering. Zuse remained affiliated with them for the duration of the war and worked on the Z2 machine during that period and the Z3, the *first functional tape-stored-program-controlled*, in other words *programmable*, computer that became operational in 1941. In the same year, he formed the first company ever known to be established with the unique purpose of developing computers. Z3 used a punched film for storing the sequence of program instructions. With the ability to convert decimal to binary and back again, the machine appeared as the *first digital computer*. Z3 was recognized as Turing complete in 1998 and there exists a reconstruction of the computer in the Deutsches Museum in Munich. Zuse almost finished the construction of Z4 as the Red Army headed to Berlin in 1945 where he left the city for Bavaria with his machine that he would complete in 1950, the *first commercial computer* ever known. It is noted that his other machines were destroyed in the Allied bombing of Germany. Apart from the machine constructions, Zuse is known as the designer of the *first high-level programming language* called “Plankalkül”.

In the United States, Harvard Mark I was designed by Howard Aiken supported by IBM as a large *electromechanical calculator* to conduct large computations automatically. It was also

called the IBM Automatic Sequence Controlled Calculator (ASCC). Aiken was influenced by Babbage's design ideas of the Difference Engine and the Analytic Engine to conceptualize the machine that was completed in 1943 and presented to the Harvard University in 1944. As a novelty to the existing mechanical, electromechanical and analog computational devices, John Atanasoff worked on developing a digital machine and he designed a machine to solve linear equations using Gaussian elimination. He published his design in the summer of 1939 and worked together with his graduate student, Clifford Berry to build the Atanasoff-Berry computer (ABC) until 1942. The working prototype is recognized as *one of the earliest electronic digital computers*. ABC was a *specific purpose computer*, not a general-purpose machine. The Electronic Numerical Integrator and Computer (ENIAC) on the other hand is known as one of the *first large general-purpose digital computers*. The construction of the machine was initiated in 1943 at the University of Pennsylvania under the pillars of US Army's Ballistics Research Laboratory. Presper Eckert as chief Engineer and John Mauchly as a consultant were part of the project team for ENIAC. The machine was in operation between 1946-1955 and it was used to integrate ballistic equations and to calculate the trajectories of naval shells. It is notable that the emergence of ENIAC was pioneered by Zuse's Z3 machine in Germany, the ABC in the United States, and the Colossus computer developed in England. The ENIAC being a fixed-program computer required it to be physically rewired, or in other words physically reprogrammed, to perform different tasks. Efforts to overcome this limitation led to the development of the *stored-program concept*, and EDVAC was born as a successor to ENIAC.

John von Neumann's report on EDVAC dating back to 1945 was published with reference to a contract between the United States Army Ordnance Department and the University of Pennsylvania and introduced von Neumann architecture and the stored program concept in detail (Neumann, 1945).

The logical control of the device, that is the proper sequencing of its operations can be most efficiently carried out by a central organ. If the device is elastic, that is as nearly as possible all purpose, then a distinction must be made between the specific instructions given for and defining a particular problem, and the general control organs which see to it that these instructions – no matter what they are- are carried out. The former must be stored in some way... (Neumann: 1945, p. 3-4)

Accordingly, the new approach was to store the program in memory and update it whenever the task to compute was changed in the memory of the computer instead of changing physical wiring. EDVAC was implemented based on that concept in 1949.

In England, secret efforts to break Germany's communication codes during the Second World War influenced the development of computers. Tommy Flowers, the British engineer guided the team that designed Colossus with the purpose of decoding the top-level encrypted German military communication sent by German High Command to its commanders and thereby constructed one of the earliest electronic computers. The British and American Intelligence was supplied with important information on German military plans related to the D-Day invasion as a result that eventually supported the success of the Normandy landings and contributed to the defeat of Nazi Germany. Bletchley Park was the base place for code-breaking work in England during war time. The secret messages encrypted by the German Enigma machine were previously cracked by the electro-mechanical device named “the Bombe” that was mainly designed by Alan Turing. The settings of the Enigma machine were deduced by the Bombe. Max Newman was at the head of the British research to decode Lorenz SZ42 machine encrypted German cipher. Alan Turing introduced Flowers to him, and this opened the path to the proposal of Colossus Mark 1 as an alternate electronic machine in 1943 to break the code. The prototype was made available in 1943 whereas the working version in early 1944. Its successor Mark 2 Colossus was in operation in June 1944 just prior to the Normandy landings and it greatly contributed to the British to monitor the German behavior in response to their deception tactics. The original Colossus machine was constructed at the Post Office Research Station at Dollis Hill in London, and it was designed to estimate by trial and comparison the key combinations for the Lorenz machines that were coded based on the Vernam cipher. Therefore, the intercepted message was not decrypted entirely. The Colossus Mark 1 machine was not a general-purpose computer but was designed for code breaking purpose specifically. It was a semi-programmable machine.

Researchers including Frederic Williams, Tom Kilburn, and Geoff Tootill were working on the design of a stored-program computer under the roof of the University of Manchester. According to the design, desired compute tasks should be defined by computer instructions and stored in memory. Whenever a change in the compute task was required, a different set of instructions, namely a different program, should be loaded into the computer memory and executed. The

University Manchester Small Scale Experimental Computer (nick name “Baby”) was developed as the *first stored-program computer* and successfully executed in 1948 running for 52 minutes. The team in Manchester developed the prototype “Baby” further, and in 1949, the Manchester Automatic Digital Computer (MADC), also known as Mark 1 became available. The programs were entered into the machine in binary format to define the set of instructions. Mark 1 influenced later computer developments including Ferranti’s Mark I general-purpose computer of 1951 and early IBM computer designs such as the IBM 701.

The initial computers designed and built during the Second World War opened the path to the introduction of initial commercial computers developed at various locations around the world. UNIVAC I computer designed by John Mauchly and Presper Eckert of EMCC for the US Census Bureau for business and administrative use, the LEO I computer developed by J. Lyons and Co. in England in partnership with Cambridge University for business use, the Z4 computer developed by Zuse KG in Germany, the Ferranti Mark I developed by Ferranti in England as an improved version of Manchester Mark 1 as one of the earliest general-purpose electronic computers, and the CSIRAC developed by CSIR in Australia that is known as the first digital computer to play music are among the earliest commercial machines.

The Cold War starting from late 1940s led to an arms race between the United States and the former Soviet Union. It was clear that computer technology would play an important role in the race to strengthen against threats. These developments in the defense industry played a driving role in the design and development of more powerful computers. The Semi-Automatic Ground Environment (SAGE) was designed as an air defense system automated for tracking and intercepting enemy aircraft in North America and remained in use between late 1950s until the 1980s. Another important factor was to develop more powerful and affordable computers for the needs of businesses, universities, and government. This motivated vendors to introduce computer families in the 1960s, instead of large proprietary mainframes. Customers would be able to switch between the options offered depending on their needs, moving from a smaller, cheaper computer in the family to a larger one as their needs increase. The vacuum tube multiplier introduced by IBM in 1943 enabled a shift from electromechanical to electronic machines with a faster, smaller, and easier to replace alternative to the formerly used electromechanical switches. IBM 701 was developed as the first large computer based on vacuum tubes in 1952 and followed by intermediate size IBM 650 and subsequent families. The

invention of the transistor by William Shockley and others in the Bell Labs in late 1940s was in paradigm shift and served alternative to the existing use of vacuum tubes for the construction of computers. This resulted in the development of smaller, faster, and more reliable devices eliminating various disadvantages of the vacuum tubes. Another revolution in the computer technology was the invention of the integrated circuit by Jack Kirby of Texas Instruments that combined multiple transistors on a single chip of semiconductor material. Various separated components making up the hardware of a computer such as the transistors, resistors, capacitors, and wiring circuitry could now be integrated and interconnected on a single chip made of silicon or germanium that eventually enabled the design of faster and more powerful computer with less cost and smaller in size starting from the 1960s. Minicomputers, smallest general-purpose computers, emerged as low-cost machine alternative to large mainframe computers from this flow. Intel's invention of the microprocessor in 1971 enabled large-scale integration of many transistors onto a small silicon unit and transformed computing by placing processing power on a tiny chip. This revolution led to the development of modern computer devices eventually including personal computers, tablets, and mobile phones.

During central decades of the twentieth century, the intelligent machine was an idea whose time had come. The computer provided the necessary medium to realize the aspiration of creating humanoid intelligence. Moreover, the set of events, especially, the paradigm shifts from the physicist's concept of energy to the cyberneticist's concept of information and the interdisciplinary efforts to understand psychological and biological phenomena and formalize them in mathematical terms, encouraged the aspirations and efforts in realizing artificial intelligence. John McCarthy, a young assistant professor of mathematics at Dartmouth College had been working on these matters. McCarthy, being inspired by the interdisciplinary convergence on the research conducted on intelligent machines, suggested that scientists working on these issues should spent the summer of 1956 together in a conference to contribute on the overall progress. This conference became the first event where the term *artificial intelligence* was officially used (McCorduck et al., 1977).

2.2.4 Emergence of AI as a separate discipline

The Dartmouth College conference of 1956 that took place in Hanover in New Hampshire is recognized as the event where the conceptual foundations of artificial intelligence were laid.

Although the use of the term “artificial intelligence” was promoted by John McCarthy, the key organizer of the event, there was no consensus among the scientists in the field on choosing this term at the beginning. For example, Herbert A. Simon and Allen Newell who were among the invited participants of the event, preferred to use the description “complex information processing system”. Due to the interdisciplinary nature of the new science AI, the researchers had different views and interests on the field, but one common goal which was to find out whether machines could demonstrate behavior that would be perceived as intelligent by human individuals (Vayre, 2021).

A proposal was submitted to the Rockefeller Foundation for a two-month, ten-person study of artificial intelligence to be conducted at the Dartmouth College. The authors of the proposal were John McCarthy from the Dartmouth College, Marvin L. Minsky; a Harvard Junior Fellow in mathematics and neurology, Nathaniel Rochester; the director of information research at IBM's research center in Poughkeepsie, N.Y., and Claude Shannon; at that time a mathematician from the Bell Telephone Laboratories (McCorduck et al., 1977; McCarthy et al., 1955).

The aim of the Dartmouth College event was stated in the proposal:

The study is to proceed on the basis of the conjecture that every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it. An attempt will be made to find how to make machines use language, form abstractions and concepts, solve kinds of problems now reserved for humans, and improve themselves. We think that a significant advance can be made in one or more of these problems if a carefully selected group of scientists work on it together for a summer. (McCarthy et al.: 1955, p.2)

As Luger (2021) highlights, this statement starts with the assumption that the mechanisms of intelligence can be precisely understood and automated. Automation is the expression of artificial intelligence in the form of computer programs. Towards the end of the proposal, authors added “For the present purpose the artificial intelligence problem is taken to be that of making a machine behave in ways that would be called intelligent if a human were so behaving.” (McCarthy et al.: 1955, p.11). This statement can be related to the Turing test, in other words, a machine is called intelligent if interrogators communicating with them cannot

identify whether they are interacting with a human or a machine (Luger, 2021). Accordingly, the Dartmouth workshop was initiated based on the assumption that machines that could simulate human intelligence were intelligent and promoted the vision that human intelligence in future could be sufficiently well understood to describe for machines to automate intelligence by the help of computer programs. Moreover, the Dartmouth proposal attracted the idea of conducting studies in multiple fields related to intelligence due to the research area's multidisciplinary nature.

It is reported by McCorduck et al. (1977) that Rockefeller provided financial support for the event where the leading four researchers; McCarthy, Minsky, Rochester, and Shannon, invited other interested participants including Trenchard More, Arthur Samuel of IBM, Oliver Selfridge and Ray Solomonoff of MIT, Allen Newell and Herbert Simon from the RAND Corporation and Carnegie-Tech in Pittsburgh to the event. Apart from them, additional visitors were invited to attend the conference including Alex Bernstein, a programmer from IBM in New York City at that time, to talk about his chess playing program under development. McCarthy did not prepare a report for the sponsoring Rockefeller Foundation about the conference event, yet there was a long paper submitted which was authored by Solomonoff (Kline, 2011).

The conference was designed to look for a solution for some of the artificial intelligence problems as it was listed in the proposal. These were classified under the seven pillars addressing the programming of automatic computers, formulation of use of a language by computer, advancing the theoretical work on neuron nets, developing a theory of the size and efficiency of computer calculation, studying the self-improvement of machines, formulation of machine abstractions of sensory and other data, and the computational randomness in relation to creativity (McCarthy et al., 1955). The conference researchers were looking for theories, abstraction and formalization of the new science inspired by the human intelligence.

In the proposal for the summer research project on artificial intelligence, McCarthy highlighted his interest on artificial languages whereas Minsky focused on abstraction models of environment combined with external experiments by which machines would look for solutions. Rochester was looking for originality in machine performance by introducing randomness. He was researching on programming neural nets while looking for originality by inserting randomness into this brain modeling. McCarthy concentrated on abstraction and logical

formalization using mathematics rather than following the brain-model approach. He was interested in the relation of language to intelligence. Finally, Shannon's focus was on the application of the information theory to machines and brain models and studying the brain model approach to automata (McCarthy et al., 1955).

The report about the fifth and sixth weeks of the conference (Trenchard, 1956) survived to date and supports the view that McCarthy was seeking for logic to define a language for expressing problems. He aimed developing a generative program as part of a general problem-solving system which would be capable of generating programs. The design of a chess playing machine was also occupying his mind. Minsky, on the other hand, was working on heuristic problem solving based on a flexible memory model of the environment where the machine was present. The designed machine would function after a humanlike model in a simple physical environment with the capability of developing in its memory a model of the environment and its own physical structure.

Artificial intelligence is historically seen related to and has diverged over the time from cybernetics and automata studies, as Kline (2011) explains. The MIT mathematician Norbert Wiener referred to problems around communication control and statistical mechanics in his groundbreaking book about Cybernetics of 1948 and stated that "We have decided to call the entire field of control and communication theory, whether in the machine or in the animal, by the name Cybernetics, which we form from the Greek κυβερνήτης or steersman." (Wiener:2019, p. 18). In the foreword of the reissue of the book, Doug Hill expresses:

The most fundamental conviction of cybernetic theory is that it all comes down to messages (i.e., information) sent and responded to (i.e., feedback). The functionality of a machine, organism, or society depends on the quality of those messages. Faithful exchanges of information allow the machine, organism, or society to maintain a state of homeostasis. Information corrupted by various forms of noise leads to the opposite. In Cybernetics, Wiener calls the mass media of his day the single greatest anti-homeostatic influence in modern society. (Wiener: 2019, p. xi).

Although media studies are out of the scope of this thesis, it is interesting to note Wiener's observation of the impact of information (technologies) on society.

Norbert Wiener questioned the possibility of constructing a chess-playing machine in Cybernetics and if possible, whether this would mean the approximation of the potentialities of the machine and the mind (Wiener, 2019). The study of the analogy between machines and human brain was not new. The paper of 1943 with the title “A Logical Calculus of the Ideas Immanent in Nervous Activity” by the neurophysiologist Warren McCulloch and mathematician Walter Pitts is recognized as the publication where the first computational model of a neural network was proposed (Url-3).

The machine-mind analogy was broadly studied at the Macy Foundation cybernetics conferences chaired by McCulloch in the years follow. Apart from the chess- playing computer, Wiener discussed set of cybernetics robots including William Grey Walter’s tortoises that were designed to simulate human like psychological and neurological functions. It is claimed that cybernetics later divided into three main paths of minimal self-organizing systems (represented by William Rosh Ashby, the inventor of homeostat²), simulating human thought (represented by Alan Newell and Herb Simon), and AI (represented by John McCarthy and Marvin Minsky) where there are historians supporting the view that cybernetics would be an origin point of the early artificial intelligence (Kline, 2011).

It is further claimed that John McCarthy organized the Dartmouth Conference in the 1956 influenced by his experience in co-editing the *Automata Studies* with Claude Shannon, the inventor of *information theory*. Automata was described by Shannon as follows:

... an interdisciplinary science bordered mathematically by symbolic logic and Turing machine theory, bordered engineering-wise by the theory and the use, particularly for general non-numerical work, of large scale computing machines, and bordered biologically by neurophysiology, the theory of nerve-nets and the like. Problems range from Godel-type questions (relating to Turing machines and decision procedures), to questions of duplication, of various biological phenomena in a machine (e.g., adaptation, self-reproduction and self-repair). (Shannon: 1958, p.123).

² Homeostat was defined as an electromechanical device that adapted to changes in its “environment” through a process of self-organization, by randomly selecting states that would eventually lead to stability (homeostasis). (Kline: 2011, p. 7)

McCarthy and Minsky worked under Shannon at the Bell Labs in the summer of 1952. Shannon, because of his interest in cybernetics and automata, was interacting and collaborating with the scientists in the area while keeping focus on the information theory. He together with McCarthy invited other scientists in the area to contribute to their volume on automata. W. R. Ashby, J. D. M. Mac Kay, M. L. Minsky, E. F. Moore, and J. von Neumann were contributing researchers amongst others where eventually the overall work submitted was divided by C. E. Shannon and J. McCarthy into categories of Finite Automata, Turing Machines and Synthesis of Automata in the Automata Studies published by the Princeton University Press in 1956 (Ashby et al., 1956; Kline, 2011).

John von Neumann was aware of information theory and started exploring automata theory along with a theoretical background on McCulloch-Pitts' neural networks and the Turing machine. Shannon (1958) highlights his major contributions to automata theory as to the problem of designing reliable machines using unreliable components, that is like the communication theory challenge of transmitting an entire code in a reliable manner despite the poor reliability of individual symbols making up that. Von Neumann attempted to define a formal structure for automata. He also worked on self-reproducing machines that are described in Shannon (1958, p.126) as a formulation of "... a simple and abstract system of "machines" which are capable of constructing other identical machines, or even more strongly, capable of a kind of evolutionary process in which successive generations construct machines of increasing "complexity".". Whether automata could reproduce themselves remained a question mark; however theoretically - like the Turing machine-, there could be a universal constructing machine which by proper programming could be designed as a self-producing machine. During the mid 1900s, von Neumann also had a great interest in analyzing the relation between the central nervous system and large-scale computers of the time (Shannon, 1958). He identified both similarities and differences. There was a distinction made between internal language used for the computation in human brain and the external language used for communication with others. From there it was deduced that logics and mathematics of the central nervous system should be designed somewhat different than our natural languages.

In brief, there had been a notable amount of scientific activity around the middle decades of the last century by researchers with different scientific and academic backgrounds and these directly or indirectly contributed to the emergence of artificial intelligence as a new science.

2.2.5 AI seasons in the history

Many smart devices that have pushed the boundaries of human imagination in the past have become possible thanks to developments in artificial intelligence technologies and its ecosystems, and it seems that they will continue to influence our lives beyond our imagination in the future. Although it was established as an academic discipline in the 1950s, it took half a century for the scientific framework of AI to be established and put into practice. This historical progression, characterized by periods of both growth and decline, is often metaphorically described in terms of seasons: the spring, summer, winter, and harvest of artificial intelligence. This subsection is based on the history of AI summarized in Haenlein and Kaplan (2019).

In 1942, American science fiction writer Isaac Asimov based his short story “Runaround on the Three Laws of Robotics” which are described as follows:

(1) a robot may not injure a human being or, through inaction, allow a human being to come to harm; (2) a robot must obey the orders given to it by human beings except where such orders would conflict with the First Law; and (3) a robot must protect its own existence as long as such protection does not conflict with the First or Second Laws. (as quoted in Haenlein and Kaplan: 2019, p.2).

Asimov's work, even in science fiction, is important for inspiring scientists in the fields of robotics, artificial intelligence, and computer science, including American cognitive scientist and a leading figure in the development of AI, Marvin Minsky. At this time, British mathematician and the conceptual father of artificial intelligence, Alan Turing, was working on a code-breaking machine called ‘The Bombe’ for the British government. The Bombe, which would break the Enigma code used by the German army in World War II, is generally considered the first working electromechanical computer. The fact that this invention succeeded in breaking the Enigma code, which even mathematicians found impossible, might have motivated Turing further researching about the intelligence of machines. Turing’s 1950 article “Computing Machinery and Intelligence” and the *Turing Test* introduced there was groundbreaking. According to the Turing Test, it was considered sufficient criterion to say that a machine was intelligent if a human being was not able to distinguish the machine from another human being as a result of their interaction with the machine versus with the other human being. The word “artificial intelligence” was first officially used in the 1956 Workshop, which lasted

approximately eight weeks at the Dartmouth College in New Hampshire under the leadership of computer scientist John McCarthy. This important event also represents the beginning of the spring of artificial intelligence. The conference was followed by a period of significant achievements that fit into nearly twenty-year period that has been called the summer of artificial intelligence. The ELIZA computer program, developed by Joseph Weizenbaum at the MIT between 1964 and 1966, appeared as a natural language processing tool that could simulate human conversation. Another success story was the General Problem Solver program, developed by Nobel Prize winner Herbert Simon and RAND Corporation scientists Cliff Shaw and Allen Newell, that could automatically solve simple problems such as the Towers of Hanoi. These developments encouraged significant funding for artificial intelligence research and enabled more projects. The period was so optimistic that Marvin Minsky predicted in a 1970 interview with the Life Magazine that a machine with the general intelligence of an average human could be developed within three to eight years. However, this never happened. Moreover, in 1973, while the US Congress began to harshly criticize the high investments in AI research, British mathematician James Lighthill also examined the optimistic perspective of AI researchers in a report he published as a result of being commissioned by the British Science Research Council. This report claimed that machines would be far from reaching the ability of common-sense reasoning. The British government ended its support for AI research at universities except Edinburgh, Sussex and Essex soon followed by the US government similar actions and the winter of artificial intelligence began. Apart from the reactive actions of the US DARPA, which were triggered by the Japanese government's intensive funding of AI research in the 1980s, lack of interest on artificial intelligence research did not change much in the following years. The initial faith in AI decreased due to lack of progress in AI and not meeting the high expectations and this was based on the design of the early systems such as ELIZA and the General Problem Solver which attempted replicating human intelligence by *Expert Systems*. These systems were basically designed according to the assumption that human intelligence could be formalized by a set of rules, in other words as if-then statements. This approach functioned well in certain domains as it was realized in IBM's Deep Blue chess-playing program defeating world champion Gary Kasparov in 1997. It was relying on high processing capability of the machine using tree search method applied on a huge number of possible moves per second to find out the optimal next move. However, Expert Systems were a weak approach in domains that were not appropriate for such formalizations such as face recognition tasks

which were requiring interpreting external data correctly, learning from that data to apply the learnings for future goals and tasks by adaptation. In that sense, due to the lack of those learning characteristics, Expert Systems did not prove to be true AI. Already in 1940s, the Canadian psychologist Donald Hebb developed a theory of learning inspired by the process of the neurons in the human brain. Statistical methods for achieving true AI were under discussion. Research on artificial neural networks was initiated yet paused in 1969 when Marvin Minsky and Seymour Papert demonstrated that computers did not have the processing power to realize them. In the twenty-first century, artificial neural networks made a real comeback in a further sophisticated form of deep learning. In 2015 AlphaGo program by Google beat the world champion in the board game Go and stroke out the long-lasting belief that computers would never be able to beat a human Go-champion. Artificial neural networks and Deep Learning were heavily utilized in most of the artificial intelligence applications ever since than including image recognition and speech recognition algorithms. The statistical advances in AI of the past are harvest today which is also referred as the fall period of artificial intelligence (Haenlein and Kaplan, 2019).

2.2.6 A chronological summary of AI

Historical narrative of artificial intelligence can be itemized in terms of a chronological summary throughout the time. This section compiles important milestones in the history of artificial intelligence up to the early twenty-first century, drawing upon citations and combining relevant quotes from McCorduck and Cfe (2004, Time Line: The Mechanization of Thinking), Mijwel (2015, p.3) and Rai (2024, p.1-21).

Late First century :

- Heron of Alexander builds automata working with water and steam power.

Early thirteenth century :

- Ebu'l-Izz bin Rezzaz el-Cezeri, one of the pioneers of cybernetic science, has made water-operated automatic controlled machines.

Fifteenth–sixteenth century:

- Mechanical clocks, the first modern measuring machines, appear in European towns.
- Paracelsus provides the recipe for a homunculus, an intelligent “little man”.

Seventeenth century:

- Automata appear on European clocks or are produced to work alone as amusements for the rich.
- Wilhelm Schickard invented a mechanic and a calculator capable of four operations.

- Blaise Pascal invents a mechanical calculator, the Pascaline.
- Treatise on Man, by René Descartes, is published posthumously and codifies the mind/body problem.
- Gottfried Wilhelm Leibniz has developed a binary counting system that forms the abstract basis of today's computers.
- Leibniz invents the Step Reckoner, an improved mechanical calculator, and envisions a universal calculus of reasoning to decide arguments mechanically.

Eighteenth century:

- Philosophers (Leibniz, Spinoza, Hobbes, Locke, Kant and Hume) and scientists (La Mettrie, Hartley) try to formulate laws of thought.
- Jacques de Vaucanson presents his mechanical duck to the European public.

Nineteenth century:

- Literary artificial intelligences proliferate, such as Hoffman's The Sandman, Goethe's Faust (part II), and Mary Shelley's Frankenstein; the beginning of empirical psychology.
- Charles Babbage begins but never finishes the Difference Engine.
- Ada, Countess Lovelace, publishes her account of Charles Babbage's Analytical Engine.
- George Boole publishes An Investigation of the Laws of Thought.
- von Kempelen's fraudulent chess-playing machine perishes in a fire.
- Herman Hollerith conducts the US census using machines that encode information on punch cards.

Twentieth century:

- Artificial intelligence is born as an interdisciplinary field and implemented with the emergence of digital computers.

Before 1940s

- Torres y Quevedo builds electromechanical machines for chess endgames.
- "Robot" introduced into English in a London production of Karel Capek's play, R.U.R., Rossum's Universal Robots.
- Kurt Gödel introduced the theory of deficiency, which is called by his own name.
- Alan Turing proposes an abstract universal computing machine.
- In developing his Z1 computer in Berlin, Konrad Zuse realizes the technology will eventually become an artificial brain.

1940 – 1950 Incubation Period

- Automatic decryption of German intelligence messages undertaken by Turing and others at Bletchley Park, England.
- McCulloch and Pitts publish "A Logical Calculus of the Ideas Immanent in Nervous Activity".
- Rosenblueth, Wiener, and Bigelow publish "Behavior, Purpose and Teleology", introducing the term cybernetics.
- Turing writes a pioneering, but unpublished paper, "Intelligent Machinery".
- ENIAC (Electronic Numerator, Integrator and Computer) developed by Eckert and Mauchly, started to operate.

- Norbert Wiener publishes *Cybernetics*; Grey Walter builds his electromechanical “turtle”.
 - John von Neumann introduced the idea of self-replicating program.
 - Mark I, the first stored-program computer, comes online at Manchester University. Turing and his colleagues attempt to program it to play chess.
- 1950 - Important Contributions to the birth of AI
- Turing publishes “Computing Machinery and Intelligence” proposing the Turing Test.
 - Claude Shannon publishes a detailed analysis of chess-playing as search.
 - Marvin Minsky and Dean Edmonds built the SNARC at Harvard, using 3,000 vacuum tubes to simulate a network of 40 neurons.
 - Noam Chomsky’s Generative Grammar and developments in formal grammar from logic provides new insights into linguistics and language theory.
 - Isaac Asimov offers his “Three Rules of Robotics” in *I, Robot*.
- 1950 – 1960 Birth of AI
- The first artificial intelligence programs for the Mark 1 device were written.
 - Arthur Samuel begins work on a checkers playing machine that learns, and eventually competes with human champions.
 - Shannon begins developing chess-playing programs at MIT, contributing to early AI research in game-playing algorithms.
 - The development of FORTRAN, one of the first high-level programming languages, starts, facilitating future AI programming.
 - Newell, Shaw, and Simon completed the Logic Theorist, one of the earliest programs for automatic theorem proving. IPL (Information Processing Language), the first list-processing language was created.
 - Birthplace of AI in 1956:
 - Dartmouth Conference, where John McCarthy proposes the term “artificial intelligence” and Newell, Shaw, and Simon demonstrate the first working AI program, the Logic Theorist.
 - Automata Studies: John McCarthy and Claude Shannon edited a volume that lacked a strong focus on AI.
 - Machine Translation Efforts: The U.S. National Research Council funds projects to expedite the translation of Russian scientific papers.
 - John McCarthy of MIT created the LISP (List Processing Language) language.
 - Friedberg introduces genetic algorithms, proposing that small mutations in machine-code programs can lead to improved performance.
 - Frank Rosenblatt’s work on perceptrons garners attention, advancing neural network research.
 - The Massachusetts Institute of Technology establishes its AI laboratory, fostering further AI research.
 - Arthur Samuel coined the term “machine learning” during a speech about teaching machines to play chess better than their human programmers.
 - Herbert Gelernter constructs a program capable of proving complex theorems.
 - Newell, Shaw, and Simon develop the General Problem Solver (GPS), a significant AI program for problem-solving.

1960 – 1970 Excitement and Limitations

- J. C. R. Licklider envisions in a series of memos what will eventually become the Internet.
- First company to produce robots for the industrial field is established.
- D. Engelbart develops the computer mouse as a way of implementing his NLS (oN Line System) hypertext and collaborative workspace.
- J. Weizenbaum's ELIZA, an artificial intelligence program, interactively mimics a psychotherapist.
- Daniel Bobrow's STUDENT program was one of the first natural language processing systems that solved algebra problems from everyday language.
- A report reveals the limitations of machine translation for scientific text, leading to the cancellation of U.S. government funding for academic translation projects.
- Minsky and Papert's book Perceptrons demonstrated the limitations of singlelayer perceptrons.
- Arthur Bryson and Yu-Chi Ho introduced the backpropagation learning algorithm for multilayer networks.
- ARPANET, the precursor to the Internet, is established.
- The first animated robot "Shakey" was produced at Stanford University.

1970 – 1980 Knowledge-Based Systems

- At Stanford University, J. Lederberg, Edward Feigenbaum, and Carl Djerassi initiated the DENDRAL project as the first knowledge-based expert system ever created.
- Developed by Feigenbaum, Buchanan, and Dr. Edward Shortliffe, MYCIN diagnosed blood infections using 450 rules, outperforming junior doctors.
- DARPA begins development for protocols called TCP / IP.
- The Internet has begun to be used for the first time.
- The Lighthill report led to the British government ending support for AI research in all but two universities.
- Jerry Winograd's early natural language understanding system paved the way for continuous speech understanding projects.
- The First AI Winter began due to disappointing results from early AI projects, leading to reduced funding.
- Herbery Simon wins the Nobel Prize in Economics for his theory of bounded rationality.

1980 - 1990 Booming and AI Winter

- IBM produced the first personal computer.
- Commercialization of AI begins; Japanese announce the Fifth Generation project with significant AI goals.
- Newell et al., create SOAR, an architecture for general intelligence
- Harold Cohen demonstrated the autonomous drawing program AARON(originally created in 1973) at the AAAI National Conference in 1985.
- Minsky publishes Society of Mind.
- Berners-Lee begins work on the World Wide Web at CERN in Geneva.
- The AI Winter with companies failing to meet their promises.
- Data mining fueled a new industry.

1991 – 2000: Robotics and Machine Learning

- Intelligent behavior is recognized to be collaborative as well as single-agent.
- Deep Blue defeats Garry Kasparov, world's chess champion.
- First official Robo-Cup soccer match.
- Robot pets, smart toys, become commercially available into the 2000s.



3. ALGORITHMS AND CREATIVITY

3.1 AI Approaches Throughout The Twentieth Century

Artificial intelligence research and implementation technologies went through several phases since their emergence. Symbol-based, connectionist or sub-symbolic, genetic, or emergent, and stochastic problem-solving approaches appeared, where some of them lasted and yet others became dysfunctional over time (Luger, 2021).

The twentieth century witnessed implementations of AI based on symbolic manipulation, expert-systems databases, and data-driven machine learning approaches. The symbolic approach introduced a heuristic symbolic information processor modelling of human reasoning while the expert systems attempted to formalize human knowledge as databases of ‘if-then’ rules (Ali et al, 2023). In the early years of AI, from the mid-1950s to the 1980s, the symbolic AI approach was prevalent, assuming human thought used symbols in representing objects and problems (Anantrasirichai and Bull, 2021). The neural network approaches that stem from the 1940s are implemented throughout the contemporary times based on large databases with the purpose of learning from data by computing patterns and correlations and making future forecasts accordingly (Ali et al, 2023).

Allen Newell, computer science researcher at the Carnegie-Mellon University in the United States, prepared a research paper about the history of artificial intelligence and intellectual issues in 1982, during the so called “winter season” of AI. The research was sponsored by the Defense Advanced Research Projects Agency, DARPA, in the United States. Newell acknowledged the mid-phase of the twentieth century as the official birth period of artificial intelligence as a field. In the research report, an entire list of intellectual issues linked with the key milestones in AI history were outlined. Newell admitted that the issues were not few, and he explained the diversity of problems by the fact that artificial intelligence was a field of study of various diverse disciplines and their related fields like cybernetics, operations research, management science, information theory, control theory, pattern recognition, computer science, and

general systems theory where most of them emerged during the Second World War as a new discipline. He has eventually chosen to map the intellectual issues into clusters in relevance with the emerging disciplines including cybernetic and computer science (Newell, 1983).

While providing a chronological summary, Newell (1982) evaluated the history of AI research from 1955 to 1980 as an accumulation and assimilation of progressing events rather than a narrative of shift and abandonment in time.

Cybernetics movements of the 1940s and 50s were seeking for commonalities between automatic machines and human nervous system in studying what they called “control and communication processes both in the animal and the machine”. Different approaches with contributions of multiple disciplines such as of computer science and neuroscience resulted in the emergence of *symbol-processing* and *neural nets* as two main paths in studying cognition computationally and building intelligent machines. Eventually, *cognitive science* and *artificial intelligence* were born and evolved as two distinct yet interlinked research areas (Olazaran, 1996).

The philosopher Rene Descartes was a mathematician of the seventeenth century and a rationalist like then ancient Greek philosopher Plato. He questioned whether our beliefs about the external world were true, and he attempted re-establishing knowledge and reality depending on a set of proofs. Descartes was doubting everything but his own existence that was “proven” through this self-consciousness. This was expressed by “*Cogito ergo sum*”. Descartes’ thinking being (*res cogitans*) was separated from the external world (*res extensa*) that it was connected to and interacting with. Rationalism introduced the separation and isolation of “thinking” from any sensory input from the outside world. The conceptualization of the world through abstractions and by the definition of rules governing anticipated interactions built foundational work for the subsequent *symbol-based problem-solving* approaches. Symbol-based approach in the representation of intelligence dominated AI during the twentieth century. It was enabled by mathematical vehicles such as graph theory, logic-based representations, and search strategies. Primary implementations of this approach included game playing algorithms and early design of robot controllers. Scientists were interested in the expert aspect following Herbert Simon and Allen Newell who proposed fundamental linkage between machine computation and human problem solving in their influential work of 1972, *Human Problem Solving*. Later in a paper

of 1976, they proposed the capacity for a physical system to be represented as a physical symbol system is a prerequisite for achieving general intelligence akin to that of humans. Accordingly, the intelligent agent demonstrates intelligence based on the processing of symbol expressions. This *physical symbol system* hypothesis was based on the *production system* after Emil Post's definition of computation which was also used by Ed Feigenbaum in his design of the early expert systems (Luger, 2023; Vayre, 2021).

In contrast to Cartesian rationalism defended by Descartes, the British empiricist John Locke posited that human beings are born with a *tabula rasa*, or empty slate. This perspective rejected the notion of innate ideas, suggesting instead that all knowledge was derived from our experiences within the world. His contemporary, the eighteenth-century philosopher David Hume established a critical distinction in human cognition by categorizing mental perceptions into *impressions* and *ideas*. Impressions were involuntary sensory perceptions reflecting external objects, they were not controlled by the subject. On the other hand, ideas were subject to voluntary control. Empiricists of this era argued that knowledge was generated as a result of the association of ideas corresponding to repeated experiences within our impressions. Modern theories of the human memory organization are inspired by the *knowledge as association* view that contributed to artificial intelligence approaches mainly through semantic networks, human memory, and language data structure models. Machine learning embodies the associational model in neural networks architectures and deep learning algorithms (Luger, 2023).

Neural networks originated in the 1940s as an interdisciplinary concept in computing, neuroscience, and psychology. Progress in any of the areas impacted studies in the other disciplines. The approach did not promote the explicit use of symbols and logic-based reasoning but was based on learning by capturing relations and association patterns in an application domain to interpret the unknown. Scientists of the era, for example John von Neuman, Warren McCulloch, Walter Pitts, and Donald Hebb were already working on the approach by the time *neuron nets* was defined as a significant research area for the 1956 Dartmouth College event on Artificial Intelligence (Luger, 2023). Inspired by the brain's neurons nets, McCulloch and Pitts were formalizing *artificial* neurons thereby developing computationally inspired neural architectures. In addition to that, Donald Hebb's notion of learning through modifying synaptic

connections proved foundational. This was enabled by the adjustable 'weights' of the links connecting the network's neurons.

Symbolic artificial intelligence approach was defined based on the principle that intelligence and cognition are a process of symbol manipulation and transformation. The representational structures in the system allowed problem solving as a result of that manipulation and transformation process according to a set of rules and strategies defined by the computer program. According to the approach, information processing is performed at the representational level; that is assumed as the equivalent of the mental process level in human, not the neurobiological nor the brain level. Human-like cognition processes is simulated by computational means by the manipulation of representational structures according to the programmed rules and strategies. Tasks such as pattern and speech recognition that are not easy to define and program as part of a rule-based symbol-processing system were examined by the learning capabilities of neural networks (Olazaran, 1996).

Neural net(work)s can be considered as information-processing systems made up of neurons; interconnected processing units, that interact in parallel to produce an output. Inspired by human brain-like information processing, neural nets' massively parallel architecture differs from the conventional *von Neumann* computer in design. They are not programmed but trained by a continued process of input feeding of the net, output observation and the adjusting the weights of the connections between the neurons by the algorithm, until that the system produces desired outputs according to a statistically representative set of sample input-output pairs. The processing operation of neurons can be simplified in three steps: 1-input addition, 2-comparison with a threshold value and 3-activation of the output accordingly. The separation between memory and the processor, and sequential computing by transforming binary expressions according to a set of rules and instructions given in a program are typical to *von Neumann* design of computer. Accordingly, a binary expression that is localized in the memory is transferred to the central processing unit and transformed by the program that is also stored in the memory, and eventually stored back in a different location in the memory. Unlike the *von Neumann*'s memory that is made up of discrete locations, information in the associative neural nets is distributed throughout the system's parameters. In other words, the state of the neural net is defined by the activation state of its processing units along with the values of the interconnected links which overall

constitute the knowledge of a neural-net system. Neural nets degrade gracefully; that means, they continue performing under certain circumstances even if some of their processing units do not work properly, and they are able to recognize whole patterns even if parts of them are presented to the net as input (Olazaran, 1996).

Neurobiologist Frank Rosenblatt introduced a hypothetical nervous system, a machine that was called *perceptron* in an article of 1958, and defined a theory for information storage and organization in the brain following the *connectionist* approach. Rosenblatt promoted the empiricist position that anticipated the nervous system working as a switching network. Information retention in the network was enabled by forming new connections between activity centers rather than being maintained in the form of coded representations (Rosenblatt, 1958).

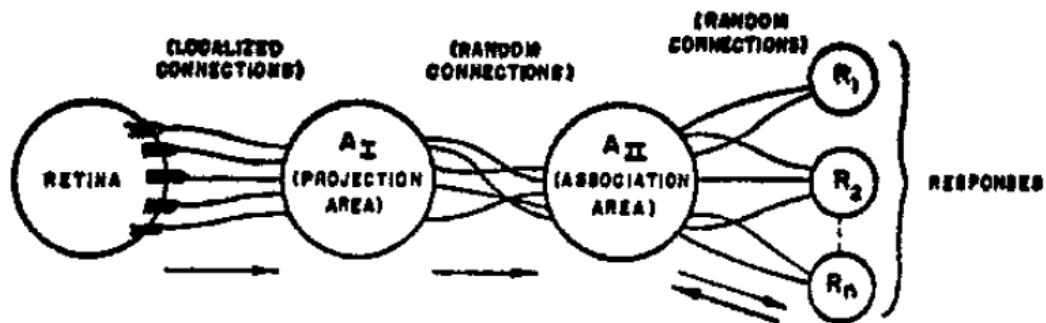


Figure 3.1 : Organization of a perceptron adapted from (Rosenblatt:1958, p. 389).

Perceptrons were yet an early family of neural networks and had their limitations. They lacked the problem solving capability for the mathematical operation *exclusive-or* as illustrated below.

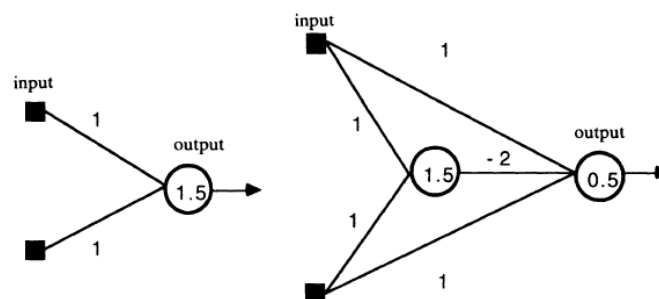


Figure 3.2 : “And” versus “Exclusive Or” Functions adapted from (Olazaran:1996, p. 625).

A simple composition of single-layer neural net with two inputs and a single output illustrates the computation of the conjunction logical function “And”. According to the example, the output unit in the simple network is only triggered if it receives activation from both input units adding up to a larger value than the threshold value “1.5”. In this setup, the computation of linearly not separable functions such as the “Exclusive Or” are not supported. Exclusive Or requires that the output is triggered only if (1,0) or (0,1) is presented as inputs. Accordingly, the system should not fire by the inputs (1, 1) and (0, 0). However, in the single-layer neural net setup, if (1,0) and (0,1) can exceed the threshold value to fire the system, the pair (1,1) can exceed that value too. Adding a hidden intermediate layer would be necessary to prevent the undesired pair from activating the output. In this purpose, to eliminate the pair (1,1), the inhibitory activation (-2) is presented to the network in the proposed illustration (Olazaran, 1996).

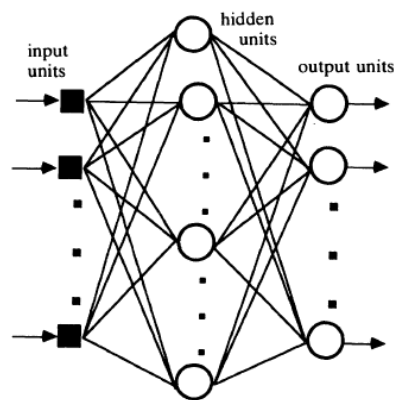


Figure 3.3 : Multilayer Network adapted from (Olazaran:1996, p. 615).

Marvin Minsky and Seymour Papert published the book *Perceptrons* at the end of 1960s and underlined the limitations of the single-layer networks, a factor that, according to Mikel Olazaran, contributed to a reorientation of research funding toward more promising symbol-based artificial intelligence paradigms (Luger, 2023).

In the world of artificial intelligence, neural network design employs an analog approach, associated with environment-driven, trained, and self-organizing cybernetic systems. On the contrary, the symbolic AI approach is characterized by its digital nature, working according to arithmetic, rationalist, and discrete structural principles. Early neural net implementation technology was limited when compared to the nascent von Neumann computers. Symbolic AI researchers contributed to the development of high-level computer languages starting from late 1950s that promoted computer

interactions by manipulation of symbolic expressions rather than solely of numbers. Newel and Simon's IPL and McCarthy's LISP languages were developed. Furthermore, John McCarthy developed the idea of CPU time-sharing which allowed on-line debugging and fixing of the programs while they were running, in other words empowered AI researchers working with the programming languages interactively from their terminals without having to wait for slow batch processes. Symbolic AI further received institutional support and funding from ARPA through the Information Processing Techniques Office directed by Joseph C.R. Licklider. Thereby symbolic AI was related to military projects for human-machine interaction by digital "command and control" and "decision support" systems. Neural nets research, on the other hand, was not strongly funded by the institution which indeed impacted the symbolic AI growing as the legitimate approach in mid 1960s, especially in the United States. The inventor of *perceptron*, Rosenblatt, however continued studying neural networks until his death in early 1970s. Various other researchers in interdisciplinary studies across the globe, particularly within neuroscience and psychology, continued to research in neural networks (Olazaran, 1996).

The 1980s marked a period of significant expansion and commercialization of symbolic AI applications, and moreover international competition, especially following the announcement of Japanese Government of its Fifth Generation Project. The rise of the expert system applications was inevitable. On the other hand, decrease in computing costs along with a wider range of access to computing resources allowed outsider researchers to initiate their own version of AI research and offered the computer as a powerful research tool in the previously abandoned approaches such as neural nets. Computer resources had been employed in the emerging interdisciplinary area "cognitive science" since 1970s that was mainly based on the symbolic approach yet required new perspectives to the mind-machine problem. Limits of symbolic AI were confronted by researchers especially in areas like pattern and speech recognition where novel approaches for computer modeling were actively pursued. In June 1979, Geoffrey Hinton and James Anderson organized a conference to solve these limitations by bringing researchers of neural net and symbolic AI approaches together. One of the outcomes of the event was the publishing of the "Parallel Models of Associate Memory" book in 1981 and later the establishment of Parallel Distributed Processing (hereafter PDP) group in the University of California-San Diego. Brain-style of

information processing empowered by parallelism was promoted by the research groups of the period including PDP. Scientist from various backgrounds continued contributing to the neural nets field. John Hopfield, a physicist from California Institute of Technology, used a method of physics to develop a new neural-net architecture with symmetric connections that was used as an associative content-addressable memory. This model was further developed by the two researchers of the PDP group, Hinton and Sejnowski, into the *Boltzmann machine stochastic multilayer net*. They developed a learning algorithm that was innovative in building a solution to the problem of learning in multilayer networks. Furthermore, researchers Rumelhart, Hinton, and Ronald Williams of the PDP group developed a learning algorithm for multi-layer perceptron-like feedforward nets, namely, the so-called *back-propagation algorithm*. Consequently, this enabled calculation of error derivatives with respect to the hidden layers in a multilayer feedforward network. In 1986, PDP researchers Rumelhart and McClelland sent a report to ARPA asking for funding support for neural net studies that was responded positively by the institution (Olazaran, 1996).

The revival of neural nets occurred in the 1980s with the introduction of Boltzmann machines and backpropagation networks that enabled solutions to the limitations addressed in the *Perceptrons* book including the exclusive-or problem. Design and construction of networks with more and larger hidden layers appeared as the next challenge. The term *deep learning* was first introduced by Rina Dechter in this regard where *hierarchical* and *deep structural learning* has also been referred to describe the approach (Luger, 2023). Notable shift in the AI implementation occurred by the connectionist approach becoming more appealing with the success of deep learning and the development of neurological theories that were providing explanations of individual and collective behavior. This new stand aimed following an adaptive approach in computer intelligence by imitating the biological nature of human cognition and engaging mathematical nature of information processing (Vayre, 2021).

Finally, a rather contemporary AI approach that will be evaluated as part of this section relates to the probability theory. It is assumed that the approach has its roots in the seventeenth century analysis of gambling and insurance. A century later, Thomas Bayes, the English cleric, was challenged to respond to David Hume's skepticism about the provability of gospel and other believer's accounts of Christ's miracles. Bayes used mathematics to demonstrate that an agent's prior expectations can be related to their

current perceptions. His response was published in the “Transactions of the Royal Society” after this death and had impact on the design of probabilistic models. In the realm of AI research, probabilistic modeling tools played a role since the 1950s. By the 1990s, they dominated computer-based language understanding and generation. Tools such as *greatest likelihood measures* were utilized. On the other hand, machine learning in AI evolved based on Bayes’ theorem utilizing a collected set of patterns that build conditions for the recognition of new patterns. Bayesian reasoning was used to build early expert systems, however for mathematically complex situations this was not applicable. *Bayesian belief network* (BBN) was developed to address those. BBN was an acyclic and directed graph where the links are conditional probabilities representing causal relationships between the nodes of the network. Any given node is independent of its non-descendants. The knowledge of its direct parents is transferred to the node. Judea Pearl received ACM Turing Award in 2011 for developing BBNs. Bayesian belief networks gained prominence by offering a reasoning framework of independent components, building a transparent representational model and suggesting a computationally useful format for causal relationships. This, eventually, significantly contributed to reducing computational costs associated with reasoning (Luger, 2023).

3.1.1 Evolution of artificial intelligence algorithms

In the nascent stages of artificial intelligence, algorithms were used to explicitly define anticipated actions for computers encoded in programming languages. The term algorithm can be described as “a self-contained sequence of instructions and actions to be performed by a computational machine” (Deng: 2018, p.172). Later, instead of coding the instructions, artificial intelligence was presented with plenty of data and learning algorithms and it was expected that the computer automatically adjusts the program that learns from a data sample and defines what needs to be done. By the introduction of machine learning, AI systems were significantly transformed by the enablement of learning from data. This empowered AI programs to autonomously acquire necessary algorithms directly from data, thereby redefining the traditional role of the programmer. This was possible because a certain pattern existed in the emerging “big data”. In other words, the hidden model representing patterns underlying the perceived data was extracted. For instance, an artificial intelligence program that was designed to analyze consumer behavior could successfully identify distinct purchasing

patterns. The differences in buying habits between individuals planning to host an invitation at home versus shopping for their babies, the factors underlying the purchasing behavior and the complex interaction in creating such data could be revealed (Alpaydın, 2022).

Alan Turing provided a description of the universal machine in his article "Computable Numbers" and a list of concrete finite steps for the "decision problem" (Turing, 1936). Thereby, he defined an algorithm as a clear definition of the solution generation procedure. Algorithms have a very important place since the twentieth century in programming and computer science in general, however the term itself dates to very old times. The first algorithm was known to be presented by Ebu Abdullah Muhammed İbn Musa el Hârizmî (780-850), of Uzbek origin, in his book *Hisab el Cebir ve el Mukabala*, using Arabic numerals (as cited in Hazar, 2022). El Hârizmî systematically described the calculation procedures in this first book known to be written on algebra. While reaching Europe, the title of the book was translated as “Algoritmi de Numero Indorum” in Latin due to the difficulty of pronouncing his author’s name. The term "algorithm" is assumed to have been introduced after this title (Hazar, 2022).

An algorithm is considered as a sequence of instructions that are executed to convert input into output, where it is important to note that not every problem has an available algorithm for its solution. For example, a formula to distinguish unwanted e-mails from the e-mails piled up in our inbox does not exist, because the classification may change over time and from person to person. Rather than relying on an algorithm coded by the human programmer, the computer may automatically derive the algorithm necessary to solve this problem, that is, to learn it artificially, based on a large sample data (Alpaydın, 2022). Artificial intelligence algorithms and programming languages evolved through diverse foundational approaches from the mid-twentieth century.

In 1957, Herbert Simon, a social scientist of his era, was exploring human reasoning and suggested the principle of the bounded rationality:

The term 'bounded rationality' is used to designate rational choice that takes into account the cognitive limitations of the decision-maker - limitations of both knowledge and computational capacity. Bounded - rationality is a central theme in the behavioural approach to economics, which is deeply concerned

with the ways in which the actual decision-making process influences the decisions that are reached. (Simon:1990, p.15)

Human reasoning, accordingly, had intrinsic constraints in addition to the external. Decision making and rational behavior resulted from information processing and perfectly rational choices could not be made by the mind due to the internal bounds of the amount it could process information (Dick, 2015). When Simon met Allen Newell at the RAND Corporation, the two argued that human mind and computers “both were “complex information processing systems” that take symbolic information as input and manipulate it to solve problems and formulate judgments by applying specific rules” (Dick: 2015, p. 625).

Simon and Newell referred to late nineteenth century theories of human reasoning and the employment of deductive rules to formalize the mind as a system. They worked on designing The Logic Theory Machine (hereafter LT) as a computer program at the RAND Corporation to explore human problem-solving behavior using elementary logic. LT was supposed to prove theorems from the “Principia Mathematica” of Alfred N. Whitehead and Bertrand A. W. Russell, a canonical reference from 1910. Their initial intention was to provide the computer with premises and inference rules and automate the proof by applying the rules to the former to deduce proofs of the theorems. However, this was an inefficient way to use. The exponential explosion of data thereby exhausted the computer resources of the 1950s quickly and was not any like human problem solving according to Newell and Simon. As a result, they employed the mathematician George Polya’s *heuristics* to design a more efficient model. Polya’s approach was not about simply deducing conclusions from axioms while working on proofs in mathematics. This included looking for patterns, experimenting with analogies, working backwards from axioms, and known theorems as well as seeking counterexamples. The deductive methodology of starting from the end; the theorem to be proved and working backwards to the axiom would produce chains of subproblems from the end problem. This heuristic search as a backward subproblem chaining was applied by Newell and Simon in theorem-proving for a complex domain. In order to implement the model, they onboarded John Clifford Shaw from the RAND Numerical Analysis Department as the engineer to the team. Simon, Newell and Shaw developed *The Logic Theory Machine* during 1955-57 at the RAND Corporation as a virtual machine, a prototype of a computer program using the

JOHNNIAC computer (Dick, 2015). Unlike conventional computation which relies on systematic algorithms, this program prioritized heuristic methods modeled after human cognitive problem-solving activities. These are articulated through a structured formal language or pseudo-code, providing a bridge between abstract human logic and the technical requirements for implementation on digital computer systems (Newell and Simon, 1956).

The implementation of LT had two main issues. The initial issue to be addressed was providing the computer the elements of logic with the propositions, axioms and inference rules and storing them in JOHNNIAC's memory. The second issue was translating the heuristic rules into computer operations for manipulating the logic elements in the computer's memory in theorem-proving. Memory management was solved by the introduction of a linked list of information structure. In this structure, the computer was enabled to use whatever memory became available. The heuristic rules on the other hand were formulated into forty-four variations of eight basic list processing operations like "find", "store" etc. A new programming language that was called the *Information Processing Language* (IPL) was introduced that contained the linked list and list processing operations (Dick, 2015).

The Logic Theory Machine was designed for solving complex mathematical problems mimicking human cognitive processes. LT's creators demonstrated problem solving capability of a computer by discovering solutions in a complex nonnumerical domain using heuristic search. Applying heuristics, rules of thumb, to discover solutions was different than applying an algorithm by rules (Penn, 2020; Vayre, 2021). LT was a functioning by identifying proofs for theorems within symbolic logic through a methodology that closely replicated human cognitive strategies (Newell and Shaw, 1957). The problem that they sought for a solution contained sufficient information and alternatives, yet there was lack of known clean-cut way of where the path to the solution was not clear at the start and vague rules of thumb were employed. LT was designed as a heuristic program for such complex problem-solving situations.

LT was designed using expertise in the fields of humanities and social sciences by incorporating key concepts of the bounded rationality theory. It is acknowledged as the *first artificial intelligence program*. Newell and Simon presented their program in the Dartmouth Summer Research Project conference in 1956. Most researchers attending the conference at that time, including the organizers John McCarthy and

Marvin L. Minsky, generally claimed that studying human cognitive processes was not a productive avenue for artificial intelligence where they advocated that AI researchers primarily should focus on formal logic (Url-4; Vayre, 2021).

John McCarthy and Marvin Minsky later developed different views on the fundamental issue of the novel science “artificial intelligence”. McCarthy considered logic as the primary focus area, whereas Minsky followed an anti-logic approach. McCarthy developed the list processing language LISP in 1958 and proposed “IF, THEN” advice taker program in 1959 (Vayre: 2021). In 1962, McCarthy left MIT AI Lab for the Stanford University AI Lab (SAIL) and worked there on knowledge-based systems. All these attempts contributed to the development of expert systems and influenced other researcher’s work.

Minsky continued at the MIT AI Lab where he received sufficient investments including from DARPA to work on establishing anti-logic approach on artificial intelligence. Further research was fostered covering the development of symbolic automatic integrator by James R. Slagle, the symbolic integration program by Joel Moses, the arch concept learning program by Patrick Winston and the LOGO programming language by Seymour A. Papert (Vayre, 2021).

Simon and Newell continued focusing on human cognition in their AI research where they developed the General Problem Solver that built the basis for the design of the most well-known expert systems. Roger C. Schank shared similar view like Simon and Newell in that AI studies should focus on human cognition, however; he was rather interested in the daily applications of intelligence than high-level intelligence and tended to basic cognition approach unlike Simon and Newell who focused on expert cognition (Vayre, 2021).

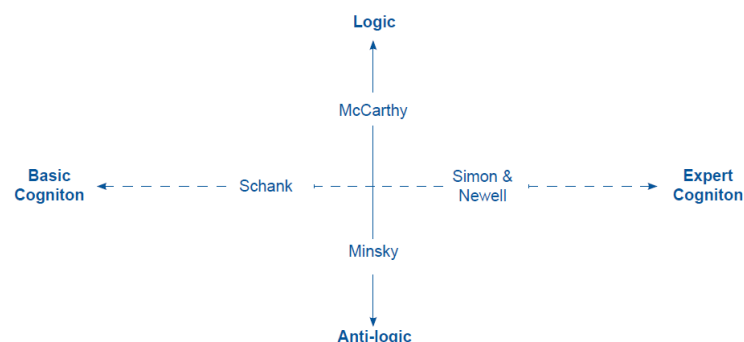


Figure 3.4 : The four main research streams in symbolic AI adapted from (Vayre:2021, p. 34).

According to Deng (2018), the evolution of the artificial intelligence can be viewed within three periods. The first wave that is starting in 1960 was based on expert knowledge engineering for application domains where symbolic logical rules were used for the design of programs. Expert systems as knowledge-based AI systems were lacking the learning ability. They were however able to take human expert like decisions based on logical reasoning usually implemented by the inference rule algorithms in the form of “if-then-else” rules. This approach worked well in narrowly defined application domains, yet it was insufficient to address uncertainty. Expert systems are still in use where the application domain is sufficiently narrow such as in the case of chess playing programs. Next wave of AI was identified by machine learning. Statistical models and simple neural networks built the core of the underlying engine of the new AI system. Training data was used by the engine to learn or tune existing parameters to keep up with uncertainties or changing conditions. Key algorithms of this paradigm are outlined as the expectation-maximization (EM), Bayesian networks, support vector machines, decision trees, and, for neural networks, the backpropagation algorithm. Deep learning is identified as the third wave of artificial intelligence approaches which differentiates from simple machine learning by the underlying deep and layered model structure of its neural networks and by the corresponding end to end learning algorithms.

Alpaydin (2022) highlights that artificial learning is built on a theory based on statistics. In statistics, it is possible to make general explanations from specific observations based on inference, and it is possible to learn based on estimation. While classification in statistics appears as discriminant analysis, this corresponds to pattern recognition, which is a more observational approach in engineering. Developments in machine learning and successes in deep learning indicated that intelligence could be achieved applying simple algorithms patiently and constantly rather than the need for inventing complex formulas and hence artificial learning became a driving force in intelligence. All these developments were a cure for the frustration caused by the old logic-based programmed expert systems in the 1980s. In the mid-80s, artificial neural network research boomed. Not only computer science, but also various disciplines such as electrical engineering, physics, statistics, psychology, cognitive science, neuroscience, and linguistics were interested in this field. The advances in very-large-scale integration (hereafter VLSI) technology that coincided with this period also

promised artificial neural networks that would distribute computation to large numbers of parallel processing units, with the capacity to create parallel hardware containing thousands of processors. Originally designed for fast image processing and transfer in graphical interfaces, the parallel computing, and data transfer architecture of the Graphics Processing Unit (hereafter GPU) was also deemed suitable and developed for machine learning. Artificial learning systems have become stronger than preceding expert systems with their success in representing uncertainties in the real-world using probability theory and models based on learning from examples that do not require programming.

3.1.2 AI problem solving strategies

Evolution of artificial intelligence problem solving strategies from symbol-based, connectionist, genetic to modern approaches are elaborated in this subsection with reference to Luger (2021).

The rationalist world view in knowledge acquisition and justification is characterized by promoting reason over experience. This application of this view is observed in the symbol and knowledge based systems. The *state-space search* that is based on the *graph theory* is the main methodology used by the “good old-fashioned AI” stemming from the 1940s and extending today. The states represent the knowledge of a problem situation at a certain stage of the reasoning process. States of a problem are searched according to well-defined rules that are eventually applied to modify the existing states. States in a graph are represented by *nodes* connected through a set of *arcs* or *links*. A graph is *labeled* by attaching distinguishing descriptors to its nodes. If the arcs have an associated direction for their next move to change a state, the graph is classified as *directed*. Leonard Euler, the Swiss mathematician of the eighteenth century is recognized as the inventor of the graph theory.

In his foundational work, Euler addressed the Königsberg bridge problem. This involved the city of Königsberg, situated on both banks of the Pregel River and encompassing two islands, all interconnected by seven bridges. The central question proposed was whether a continuous path could be walked along that crossed each of the seven bridges only once, thereby visiting all parts of the city. Euler created an alternative representation in terms of a graph and demonstrated that the walk was impossible. He analyzed the degree of the nodes by determining the even or odd

number of arcs joining a particular node to its neighbors and concluded that the graph should contain either zero or two nodes of odd degree for the walk to become possible. With more than two nodes of odd degree, just as in the scenario of the Königsberg problem, the walk was impossible. This concept later formalized as an Eulerian path. If the starting and ending points coincide, the path is then referred to as an Eulerian circuit.

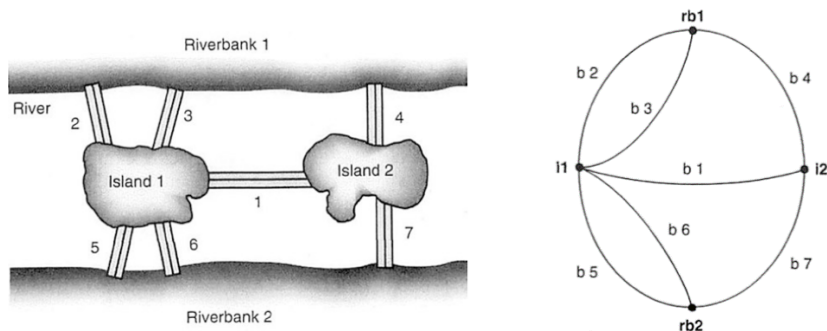


Figure 3.5 : A map of Königsberg at the Pregel river versus a graph representing the city with the seven bridges adapted from (Luger:2021, p. 79).

Various strategies are used in the state-space search to offer solutions for a specific problem. The left-to-right backtrack, left-to-right depth-first, and breadth-first search strategies are covered.

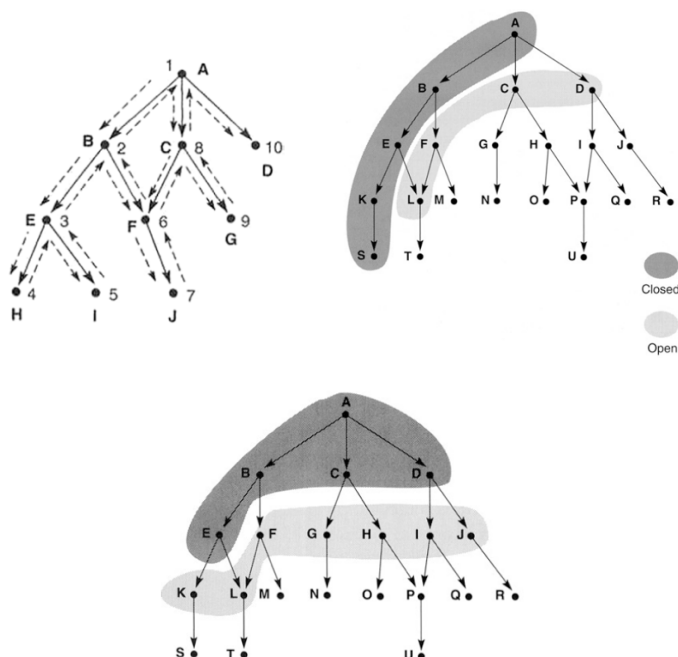


Figure 3.6 : Sample graphs demonstrating left-to-right backtrack, left-to-right depth-first, and breadth-first search adapted from (Luger:2021, p. 81-82-83).

In the *left-to-right backtrack* strategy, the left-most state is selected as the first option to search (B starting from A) where the search process is continued until reaching a dead-end (H). From there, the algorithm backtracks to the most recently visited node and proceeds according to the same pattern. Accordingly, entire graph will be visited depending on complexity and keeping track of the already visited states, by going as deep as possible and backtracking whenever a dead-end is reached. *Left-to-right depth-first* algorithm applies similar search strategy, with the additional introduction of “Closed” and “Open” lists to keep track of already visited states versus next possible states. In the remaining strategy, *breadth-first search*, the non-selected states are placed in order at the right end of the Open list. Although adding novelty to the solution practice, this type of search can be computationally more expensive than depth-first search. Nevertheless, it ensures finding shortest possible solution by preventing cycles in the search with the help of recording visited places. Additional improvements to the search algorithms are introduced for example by best-first or heuristic search and symmetry reduction to decrease the search space. State-space search is used for planning robot actions in traditional approaches. Possible states of the world are described utilizing logic-based specifications where next moves are usually decided by automated reasoning systems.

Rule-based expert systems leverage a state-space problem-solving approach. They are typically structured around a production system architecture, which aims to model and emulate human problem-solving methodologies. In the simplified description of *expert systems*, usually *human knowledge engineer* collects knowledge from the *human domain expert*. The system operates based on the domain knowledge by using a decision tree, a production system or similar algorithmic control strategy. The decision tree representation, that is used for production system-based search for the expert system, consists of an and/or graph, serving to connect the various constraints that must be satisfied by the production rules.

Within a typical production system, the knowledge base is represented as a set of *if... then...* rules. A specific action, formalized by the "then" component, is executed only when the condition described in the "if" component is met. Meanwhile, data relating to a particular situation is maintained in the working memory.

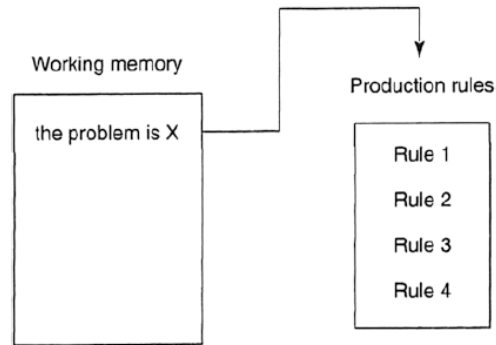


Figure 3.7 : Sample production system at the start of its operation adapted from (Luger:2021, p. 88).

The production system may operate based on a forward data-driven or goal-driven search. In the data-driven approach, the system begins with initial problem data and seeks for the most suitable hypothesis to explain it. On the contrary, in a goal-driven approach, the system captures *if...then...* rules whose conclusions match the desired goal. The corresponding premises are then loaded into the working memory and supporting subgoals are iteratively worked backward from the initial problem goal. This process terminates when sufficient subgoals within working memory are identified as true, thereby satisfying the original objective.

Expert systems have been used in various application domains. Two of the widely known early expert system solutions, MYCIN that was developed for the diagnosis of meningitis and DENDRAL used for the discovery of structure in chemical compounds, had been introduced by Edward Feigenbaum, the former PhD student of Herb Simon and one of the founders of the Computer Science Department at the Stanford University. Machine learning systems in artificial intelligence utilize large amounts of data to capture patterns directly from data using data mining technologies. Decision tree algorithms such as ID3 rely on huge number of human data. As an example, the BACON programs were created by scientists including Herb Simon and Pat Langley at Carnegie Mellon University with the aim of discovering mathematical laws to describe planetary motions based on observed data.

Graphs or decision trees, heuristics, knowledge-based systems that are encoded in rules all belong to the symbol based artificial intelligence approach. Abstraction is the key element of a symbol-based approach, where symbols are defined to represent common properties of items, structures or cases. Algorithms are used in reasoning of further properties or relationships of the abstracted elements. The symbol-based AI

approach embodies several challenges. The generalization problem is one of them that can be mitigated by introducing appropriate bias or extensive built-in knowledge to identify patterns in not so well-defined data. The semantic meaning of the symbols used in the symbol-based AI may cause further issues. Alfred Tarski suggested that “meaning” would be the product of formal logic such that given certain conditions, logical reasoning rules would produce correct results. In this context, the grounding problem was introduced by John Searle as demonstrated by the Chinese Room example. In this mental experiment, Searle, who does not know Chinese, sits in a room, and translates sentences from Chinese to English by using set of Chinese symbols and a cataloging system where he looks up the Chinese symbols and reports back the corresponding English symbols. It remains debatable whether he as a system can be recognized as a Chinese to English translation machine and whether symbols can be acknowledged as having meanings. A more general version of that leads to the argument that machines do not know or perform anything but producing their programmer’s instructions. This argument can be traced back to the nineteenth century, by the statement allegedly belonging to Ada Lovelace, that the Analytical Engine is limited to what their originators enable them to do.

Apart from following the rationalist view as presented in the symbol based applications, scientists studied association based representations, neural or connectionist networks since the 1940s as a multidisciplinary area in computing, psychology, and neuroscience. *Semantic network* was designed based on the behaviorist approach introduced in the psychology in the early twentieth century as a schematic, hierarchical and generalized representation of how humans perceive and recognize the world.

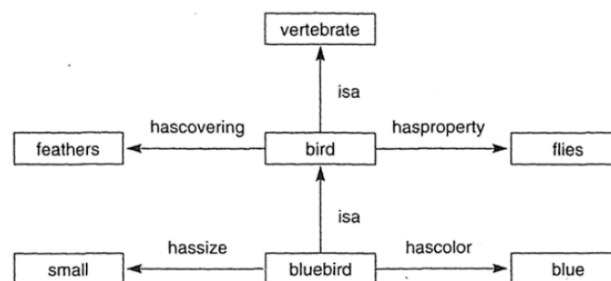


Figure 3.8 : A semantic network sample that describes a bluebird with its properties adapted from (Luger:2021, p. 19).

Neuron nets was defined as a specific research area in the 1956 Dartmouth Workshop event on AI. Neuron nets are not designed to rely on the explicit use of symbols nor the logic-based reasoning, but on relationships and associations in an application domain. Nets learn about the patterns to interpret new situations. *Neurally-inspired computation* or *parallel distributed processing* describe the neural networks. Namely, they consist of simple interacting components; the artificial neurons in AI system and achieve intelligence through learning by adjusting the connections between the neurons as they continue processing the patterns in the environment. Computation is performed in a distributed manner and problem solving occurs parallel while all neurons within a collection or layer process their inputs independent of each other and simultaneously. McCulloch and Pitts neurons demonstrated an early example of neural computing where they were capable of computing any logical function. Neural networks are constructed according to a scheme, as created by their designer, to encode patterns in their world. The representational accuracy of the scheme is important to the success of the learning process in the network. Domain patterns and connections between the components in the network are represented numerically where the transformation of the patterns is executed by the numerical operations.

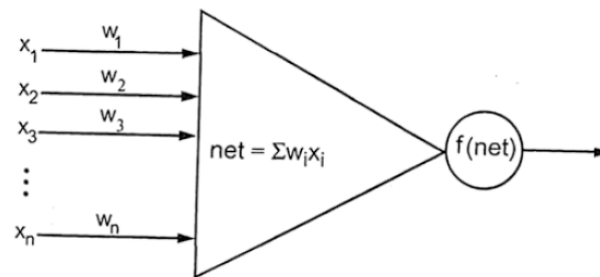


Figure 3.9 : An artificial neuron with input vector x_i , weights w_i for each input, and a threshold function f that determines the neurons' output value adapted from (Luger:2021, p. 115).

Main components of an artificial neuron consist of input signals x_i , a set of real-valued weights w_i to define connection strengths, an activation level $\sum w_i x_i$ by the sum of input signals multiplied by their associated connection weight, a threshold or bounded non-linear mapping function f to find out whether the neuron output is above an activation level to determine an on/off or a graded response. The architecture of the neural network on the other hand is defined by the network topology, in other words; by the connection patterns between individual neurons, the learning algorithm, and the encoding scheme to interpret the data placed to the network.

The algorithms of connectionist approaches are usually trained or conditioned rather than being coded in an explicit way by a program. Early AI learning models depended on psychologist Donald Hebb's argument that human learning relied on the modification of synapsis. Hebbian learning produced changes in the weight in response to localized neural processing events.

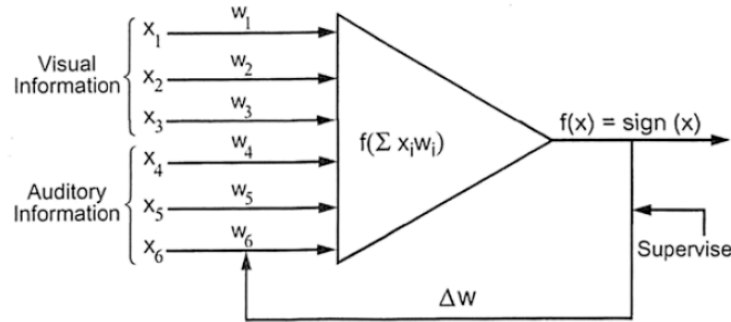


Figure 3.10 : A Hebbian network learning response for an unconditioned stimulus by ΔW adjusting weights at each iteration adapted from (Luger:2021, p. 117).

Neural network learning is identified by the three methods; unsupervised, supervised or a hybrid combination of two. In the unsupervised version, feedback to input weights by output weights does not exist. Learning occurs by adjusting weights across multiple iterations as a function of the input and output values of the neuron without any intervention to provide the correct output value. After repeated application of a stimulus, the network becomes more sensitive to that and learns to respond to that stimulus without any external supervision.

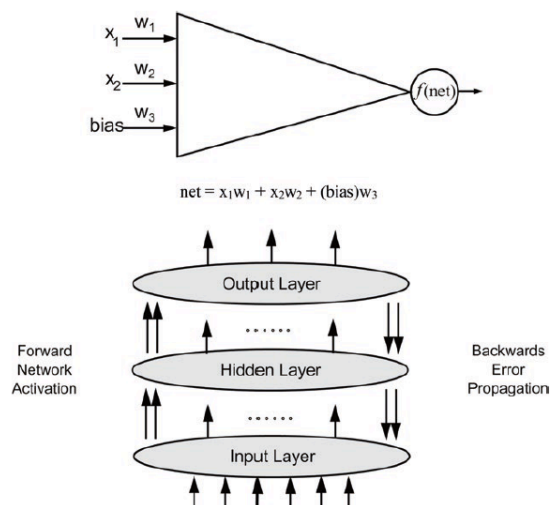


Figure 3.11 : A single artificial neuron above and a supervised learning network below adapted from (Luger:2021, p. 71).

In the supervised learning, an oracle analyzes outputs produced by the network based on the inputs and trains the network to produce correct results by strengthening the weights producing them or weakening the weights leading to incorrect output values. The emergence of Boltzmann machine and backpropagation algorithms in the 1980s demonstrated that the weights of nodes in a multilayer network could be conditioned in alignment with the expected output of the network. The neurons of that era were connected in multilayer networks where signal processing could spread errors deep in the network through connected layers and the identification of the source of the error was a quite complex task. Boltzmann machine and backpropagation algorithms were a relief to that complexity by starting with the output nodes, the errors could be propagated backward through the hidden layers. The exclusive or (XOR) problem was solved eventually. Progress in the algorithms along with the increase of computing resources over the time led to new challenges in the connectionist approach such as building neural networks with multiple and hidden layers. Hierarchical learning and deep learning emerged over time and became a critical part of modern computing.

Neural networks eventually directed attention from logic-based problem solving to a more adaptive and associative approach that functions in a similar way like human mind in perceiving patterns in a chaotic world of stimuli and in their capability of learning which counts as a strong attribute of intelligence. They were more robust in their architecture than their symbolic equivalents due to their distributed representation and redundant network structure of neurons. On the other hand, several issues remained open which require more research with regards to the semantic and neural nets. For example, inductive biases required further research both in human and machine learning. They were implicit to the network that are introduced by the choices of the scientists while designing and constructing the connectionist architecture and impacted both initial learning and the integrating of new knowledge and relationships. Generalization of appropriate solution for specific domains that can be extended to related problems and lifelong learning emerged as another challenge especially for deep learning networks. Further issues were marked as the need for transparency and accountability of neural net systems, especially if it comes to human interaction for critical decision making that can be applied to multiple domains such as health care, facial recognition, privacy, financial credit amongst others.

Artificial neural systems were inspired by the advancements in research about biological life. Several search and learning algorithms in AI were designed accordingly. Research about genetic algorithms and programming were in principle initiated similarly; they were designed after the evolutionary processes of building a population of individuals through the survival and reproduction of their fittest members. Back in the early years of AI, John von Neumann questioned possibility of computational self-replication and required level of organizational complexity in his lecture series in 1949. He was aiming to abstract the logical form of self-production from the natural process. Accordingly, he designed an automaton with two-dimensional cellular arrangement that contained many individual 29-state automata. In this setup, the next state for each of the automata was defined by its current state and the states of its four immediate neighbors were computed through a function. Von Neumann's design was implemented only in the 1990s by an undergraduate at the Princeton University, Umberto Pesavento. *Self-improvement* was also proposed as one of the problem areas to abstract and focus on for the 1956 Dartmouth Summer Research Conference on AI. This was inspired by the vision that intelligent machines would make themselves better (McCarthy et al., 1955).

Genetic algorithms base on an analogy with the biological evolutionary theory. Accordingly, computerized solution-search and learning occurs in competition for the next generation of candidate solutions for a problem. A fitness function evaluates available solutions and decides for the candidates of the new population. In the first stage of the genetic algorithms, individual solution alternatives for a problem are created and encoded in a computationally operable representation. The fitness function enters the scene in the second stage and selects the best members of the potential solution population for survival. Finally, next generation of potential solutions are constructed by the *genetic operators* given these members. The best solution can be provided from the latest generation of solutions.

Solutions are commonly represented in a binary format, that means a series of 0 and 1 bits, for genetic operators to manipulate them. After applying the fitness function, the genetic algorithm selects candidates for a recombination procedure to produce the next generation of solutions represented as binary strings. The genetic operators vary. *Crossover*, for example, produces offspring by preserving features of the parents while splitting available solutions and swapping their components to construct next

generations of the solutions. *Mutation*, on the other hand, randomly changes patterns of a single solution candidate. In this way, it may introduce an essential component for a solution that does not exist in the original candidates. *Inversion* type of genetic operator, that reverses the order of bits, may also serve to this task.

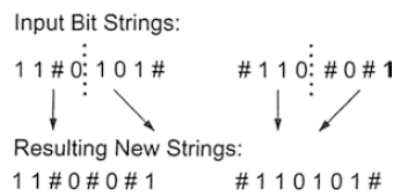


Figure 3.12 : Crossover applied on two bit strings where # represents either 0 or 1 adapted from (Luger:2021, p. 147).

Early applications of genetic algorithms utilized low level representations such as the bit strings; however, problems such as *The Traveling Salesperson*³ introduced the need for more natural encoding at a more complex representational level.

J.R. Koza suggested creating a computer program through evolution, by the application of genetic operations, in the 1990s (as cited in Luger, 2021). In *genetic programming*, the search space of initial population constitutes a randomly generated set of structures, namely hierarchically organized computer program modules. Genetic operators help transforming these structures according to a fitness measure that is used to evaluate them. A set of termination conditions are required to finalize the process like the genetic algorithms.

Koza's genetic operators were applied with LISP. Originated in the 1950s by its creator John McCarthy, the LISP is functional computer language. The program components coded by LISP are *symbol expressions* (hereafter *s-expressions*) that have natural representations like trees with the function sitting at the root and its arguments at the descends of the root. Koza's genetic operators processed the s-expressions in terms of mapping the structures into new trees or LISP program components.

Koza described by the below provided figures (as cited in Luger, 2021) sample genetic operations on LISP. The figures illustrate a process where random set of s-expressions

³ "A salesperson is required to visit N cities as part of a sales route. There is a cost, e.g., mileage or air fare, associated with each pair of cities on the route. Find the least cost path to start at one city, visit all the other cities exactly once, and return to the starting city." (Luger:2021, p. 148).

are generated initially and then two of the program components selected for fitness. They are then manipulated by the crossover operator to produce child programs.

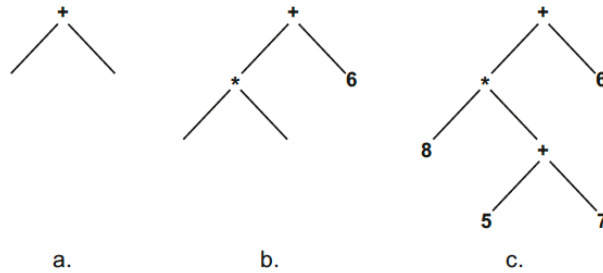


Figure 3.13 : Random generation of s-expressions with operator nodes, +, * from set F of LISP functions adapted from (Luger: 2021, p. 152).

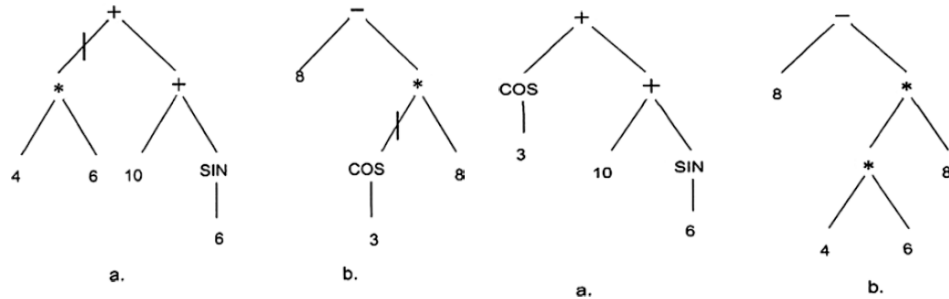


Figure 3.14 : Two programs are selected for crossover operation at the point represented by “|” on the left and child programs are produced on the right tree illustrations adapted from (2021, p. 153).

Apart from the genetic algorithms and programming, John von Neumann’s work in self-replication systems that was initiated in the 1940s impacted later the emergence of *artificial life* or *a-life*. The computing model underlying the self-replication was *finite-state machine* or *cellular automaton* that is mainly a connected graph constructed by three components: 1-a finite set of states, S , covering each part of the graph, 2-finite set of input signals or alphabet I , and 3-the state transition function F that computes next state in the connected graph for a state S given each input signal from the set of I . The input to each state is made up of the resulting value computed by function F of its present state and all its immediate neighbors. The state machines illustrate society-based adaptation considering that the next states in the graph are a function of their neighboring states. In this model, fitness is not an explicit evaluation of individual members, but it is hidden in the natural evolution by the actions of other co-evolving individuals of the population.

Simulating biological evolution remains challenging while the specific historical pathways leading to life on Earth cannot be fully explained yet. Genetic models of computation however maintain opportunities for understanding human and machine intelligence. They indicate that intelligent collective behavior is an outcome of the interaction and cooperation of independent, distributed, individual intelligent agents without the existence of a central plan. Projecting this model to the functioning of human mind still leaves open questions about the high-level cognitive abilities including the language and the understanding of the interaction between the cognitive domains as modules. The interactions of individual neurons in the biological systems might have been modeled by evolution like the construction of the modular structure of the brain. It is argued that a similar theory can be extended to social sciences for evaluating and understanding the overall dynamics of the economic markets and our social systems as a collective unit of individual and independent modules.

Genetic algorithms and a-life utilize certain level of randomness in the search and exploration, and for expanding the resulting potential solutions. The random element is usually associated with creative thinking. Remarkably, *Randomness and Creativity* was already proposed as a special topic in the Dartmouth College Conference for AI:

A fairly attractive and yet clearly incomplete conjecture is that the difference between creative thinking and unimaginative competent thinking lies in the injection of a some randomness. The randomness must be guided by intuition to be efficient. In other words, the educated guess or the hunch includes controlled randomness in otherwise orderly thinking. (McCarthy et al.: 1955, p.2)

The remainder of this dissertation report focuses on the creativity dimension of artificial intelligence.

3.2 Understanding The Emergence of AI Creativity

This section aims an understanding of creativity as a general concept and the creative process used in the production of arts within the realm of computer based applications and AI. Based on that, artificial creativity is explored through a historical review.

3.2.1 Creativity as a concept and in relevance to AI

Creativity is seen as a fundamental feature of human intelligence. It is embodied within a wide range of activities from association of ideas and generation of new ones to reflective self-criticism. Creativity goes beyond the cognitive dimension, and it involves cultural context and personality factors as well (Boden, 1998).

Creativity is the ability to come up with ideas or artefacts that are new, surprising and valuable. ‘Ideas’ here include concepts, poems, musical compositions, scientific theories, cookery recipes, choreography, jokes –and so on. ‘Artefacts’ include paintings, sculptures, steam engines, vacuum cleaners, pottery, origami, penny whistles – and many other things you can name. (Boden: 2004, p. 1).

Despite the absence of a unified definition, “novelty” and “value” are identified as the core characteristics of creativity. Accordingly, a creative product or act is expected to be original and useful (Carnovalini and Rodà, 2020; Rohrmeier, 2022).

Notably, there exist contrary approaches de-emphasizing the value of creativity for humankind. Frieder Nake (2012) begins the article “Construction and Intuition: Creativity in Early Computer Art” with a reference to Harmut von Hentig who sees creativity as a “weak concept” for which high expectations are set. Hentig concludes this based on the observation that eras and cultures are described using big and powerful words where creativity has no place in this. According to Nake, this approach has changed so radically that "creativity" became one of the most popular titles. Creativity can be positioned as a means or purpose of the activity. Hentig keeps distance from context-independent creative skills. According to him, creativity must only be concretely related to situations and contexts; it cannot exist as an abstract general concept.

Human novelty, for some view, evolves by radically changing existing accepted norms and conventions rather than in the total absence of them:

While some inadvertent artistic output may be deemed original, for the artist to be deemed to have originated something, that output needs to have some future: unless it prompts the emergence of some intellectual, artistic or socio-cultural practice, that output's originality only captures its fleeting novelty in relation to existing practices. (Delacroix: 2021, p. 1199)

The originality value of something depends on the quality of the output as well as the receptivity of the intended audience. At the individual level, originality can be associated with identity formation and authenticity whereas on the collective level a social-moral change is expected as an outcome (Delacroix, 2021).

Another aspect suggests that chance and dynamic processes play a key role in creativity, mainly as in the form of art (Dorin, 2013). The *Makapansgat* pebble, that is one of the earliest aesthetic artefacts, resembles enigmatically to human face and seems to have been created by chance. Nature provides various samples of such objects where stochastic and generative processes are the underlying forces for creativity. In music for example, the wind chimes of ancient Rome that are called *tintinnabulum*, the *dice games* of the eighteenth century that determined the sequence of musical phrases or pitches, examples of the twentieth century in *stochastic composition* and music synthesis and *improvisations* among human performers or between them and machines all are indications of the chance factor and its impact to the creative process. Natural and human-driven dynamic processes with the involvement of randomness are engaged in the production of generative art originating from the digital art movements of the 1960s (Dorin, 2013).

Generative art refers to any art practice where the artist uses a system, such as a set of natural language rules, a computer program, a machine, or other procedural invention, which is set into motion with some degree of autonomy contributing to or resulting in a completed work of art. (Galanter: 2003, p.4)

An initial random condition is used sometimes and a computer program to execute the generative processes of combination and permutation to eventually produce the ultimate artifacts. These may include a music piece or a performance (Dorin, 2013).

Vincent Tomas (1958) explored creativity in the arts during the central decades of the twentieth century just when the artificial intelligence concepts were blooming. He was suggesting that the creative act is not a purposive act where the artist would know the

targeted outcome from the beginning, yet the creative artist consciously controls the process to produce the desired product. C. J. Ducasse proposed following statement in “The Philosophy of Art”:

To say that art is conscious ... or ... critically controlled ... does not mean that it need be conscious or so controlled either antecedently to or contemporaneously with the expressive act. ... But it does mean that a critical judgment is an intrinsic, essential constituent of the productive activity called art; and indeed, not merely a critical judgment, but a favorable one.... One must be able to acknowledge the product as an adequate statement of oneself.... The telic character, which truly belongs to art since a critical moment is an intrinsic part of it, may be said to accrue to the expressive activity which is its first moment *ex post facto*. That activity is telically construed and criticized after it has occurred. And the work of art is not the product of that activity simply, but of that activity telically construed and criticized, and if need be repeated until correction of the product results, i.e., until objectivity of the expression is obtained. (as quoted in Tomas: 1958, p. 11)

Accordingly, artists apply critical control along the process of creation to their work and move them to a sensed direction without foreseeing the result of the creative activity. This approach evokes a critical point of view; sometimes it is a matter of destroying, rebuilding and repairing, and considering the act of creation not as an instantaneous moment, but as a dynamic process that occurs, lives and evolves.

Tomas (1958) was seeking for an aesthetic and artistic value in creative art. Creativity that is produced as a result of passive imagination or the art of insane was excluded from that. The creative process would start with a moment of inspiration and continue with the moment of development or elaboration driven by the critical control of the artist. The originality of the resulting product was required to qualify that as a creative artifact.

Creative ideas and artifacts are commonly referred as *novel* either psychological or historically:

A psychological novelty, or P-creative idea, is one that's new to the person who generated it. It doesn't matter how many times, if any, other people have

had that idea before. A historical novelty, or H-creative idea, is one that is P-creative and has never occurred in history before. (Boden: 2009, p. 24).

Computer models of the twentieth century fall often into the category that Boden refers to as “P-creative”. Nevertheless, historical novelty, “H-creativity”, was achieved by certain implementations as well such as in the case of the AARON program that was able to generate colored drawings novel to its human originator (Boden, 2009).

The artificial intelligence models of the twentieth century mainly focused on the cognitive dimension of creativity according to the cognitive scientist and researcher Margaret Boden (Boden, 1998). Three forms of creativity are defined by Boden (1998, 2009). Accordingly, novelty can be reached by *combination*, by *exploration*, or by *transformation*. Combinational creativity is achieved by associating known ideas and artifacts that were not necessarily directly linked before and thereby generating unfamiliar combinations of familiar items. A collage designed in the form of virtual arts is an example of this type. Exploratory creativity is achieved by exploring a conceptual space with a set of generative and, for the most part, implicit rules that represent culturally accepted style of thinking. Novelty will fit into the space defined and constrained by the generative rules, such as for a new sentence in a certain language would be generated by applying corresponding language’s syntax rules to qualify as grammatically acceptable. In the transformational creativity, unlike to the exploratory, the conceptual space is altered by the alteration of its initial rules and defining dimensions. Sometimes, the distinction between exploratory and transformational remains vague if there is no clear difference between a rule’s “alteration” versus “tweaking” of it as part of the exploration.

Combinational creativity as a natural feature of the associative memory, is the easiest to achieve for human beings because of their innate biological power. Human beings learn about the associations naturally while living in a culture. Thus, the making of the associations does not require any learning process according to this view, instead it is a natural capability. By the end of the twentieth century, this type of creativity was the most difficult for the computer to achieve as it required rich store of knowledge including the cultural knowledge to build valuable associations. The *exploratory* creativity requires domain knowledge. Experiments in Musical Intelligence (hereafter EMI) program that composes in the styles of well-known classical music composers, and the AARON, Harold Cohen’s image generating program originating in the 1960s,

fall into that type of creative computer models. Genetic algorithms (hereafter GA) were considered as promising in achieving *transformational* creativity towards the end of 1990s. GAs were able to perform random changes in a program's set of task-oriented rules as they are undergoing biological evolution. Usually, evolutionary programs also inhibit a fitness function to choose between members of new generation for use as parents in the next random rule changing. Thereby, best members are selected at each round of the task programs. Domain expertise and valuation of results emerge as main challenges in achieving computer modeled novelty, especially in the form of transformational creativity.

Boden (2009) argued that most computer models for creativity are designed by the scientist with the intention to illuminate how the creative process works in the human mind, on the contrary, the artist focus on the artistic performance of their programs in generating the creative outcomes and they do not have any interest in understanding human psychology. The artistic performance can be achieved by the interaction of a computer and human being or by the computer stand-alone as part of generative art where the AI system itself is credited with creativity. Evolutionary art is such a case where the computer becomes the producer of the novel outcomes beyond the imagination of its human programmer. Boden admits that the question of whether a computer can be ever creative is philosophical rather than scientific and remains unanswerable. Although scientific explanation for the creativity of the human being remains elusive, this study is based on the hypothesis that the computer-based experiments in the creative field have been facilitating understanding the human creativity as a phenomenon.

3.2.2 Computational creativity

Within the developmental history of machine intelligence in the nineteenth-century, Lady Ada Lovelace is recognized as a collaborator on Charles Babbage's early work of nascent computing. She famously argued against the notion of machine creativity in terms of originating anything, noting that the engine could only realize the processes that its designers "know how to order it to perform" (Boden: 2004, p.16). Alan Turing, in his ground-breaking article on machine intelligence dating back to mid-twentieth century, rephrased Lovelace's argument into the notion of "a machine can never 'take us by surprise'" (Turing: 1950, p. 450), and contested to that the surprising of an

observer would require an underlying creative mental act. Turing criticized the consciousness argument as being of a solipsist view that the only way to know a man think is to be that (hu)man⁴. He rejected the claim that the only way to know thinking is through subjective identity and suggested a test for intelligence that can be applied based on the perceived quality of the output produced, rather than by questioning the internal consciousness of the machine. Turing also quoted from D. R. Hartee in the same article and supported his view that a machine could develop the ability to learn and start thinking for itself which would eventually mean the ability to originate something.

Turing considered the ability to start something and the ability to surprise someone as similar. Delacroix (2021) argues that these are separate concepts and would only overlap at times. The co-produced surprises that lead to model change versus the trivial surprises that may for example results from a merely failed calculation or prediction are to be distinguished from each other. Only the former can be linked to Lady Lovelace's originality concept that is related to surprise and hence to Turing's question about the ability of machines to think.

During the years of the emergence of artificial intelligence, in 1959, the Turkish mathematician Cahit Arf attended a conference at the Atatürk University in Erzurum about machine intelligence. He described creativity as a distinguishing feature of human mind in the corresponding conference report and concluded that machines would resemble that level only if they can bear a random element in operation (Arf, 1959). Thereby, Arf indirectly referred to the concepts of quantum mechanics while suggesting random element for machines to address uncertainty (Sarı, 2021).

Creativity can be related to chance, chaos, randomness, and unpredictability. Within the context of creativity, Margaret Boden distinguished between a psychological novelty; the P-creative idea, and a historical novelty; the H-creative idea. According to this framework, P-creativity identifies ideas that are fundamentally new to an individual, whereas H-creativity refers to innovations that are novel within the entirety of recorded human history. Boden argued about the constraints of creativity that are enabling undefined number of possibilities within defined spaces (Boden, 2004).

⁴ Turing uses the expression "man" in the article it is assumed that he refers to human in general.

Computational creativity is achieved within a particular “conceptual space” given a set of rules and data for the computer to act random within that space, and thereby become creative and produce novel ideas or artifacts. In that sense, constraints are not assumed as the opposite of randomness. Their continuity supports that novel ideas or artifacts generated by the computer can be recognized by the receiving or interacting human being. The conceptual space in that regard provides opportunities for viewing an existing task-domain through a window that was not known or never opened before. According to Boden (2004), if there is no connection with the familiar at all, the creative outcome might become bewildering rather than surprising. In the end, there is not any scientific proof available about that yet, that the human creativity would work without any rules and constraints.

Generative systems and heuristics are referred to by Boden (2004) as the two featured computational models that are underlying machine creativity. *Generative system* stands for a structural space that encompasses computational possibilities. *Heuristic*, sometimes referred as trial and error, is a method for selectively and insightfully traveling through this space whereby sometimes transforming it. Data and action- rules together form the generative system with potentially infinite set of solutions within a search space that is pruned and used for problem solving by means of heuristics. Artificial intelligence ecosystem provides a dynamic environment for those theoretical models to be executed. Conceptual space is a kind of heuristic search-space where the AI program, in other words the effective procedure⁵ follows a set of information processing steps in conceivably choosing between possibilities while seeking for a solution. For example, the conceptual space of western music is constrained by the rules of harmony and musical tempo where the melodies can be generated by seeking through a precisely mappable landscape of musical intervals. Eventually, a tune can be constructed as a set of notes by satisfying these rules according to a procedure within the search space. The rules for an acceptable melody for human being might be intuitive, yet not easy to define and formalize. Domain specific knowledge is required.

According to an argument, artificial intelligence can produce outputs that can be attributed with creativity although lacking, where the underlying process remains a

⁵ Boden (2004) uses effective procedure in place of an executable algorithm. Boden highlights that an effective procedure does not necessarily need to be effective in terms of succeeding the action it needs to complete and that all computer programs, whether successful or not, are effective procedures.

mystery. This type of creativity is classified as “artificial” or “pseudo-creativity” to distinguish it from the human creativity (Runco, 2023). Authenticity, intentionality, originality, effective surprising⁶ and persuasiveness are listed under the key dimensions of human creativity that are doubted or lacking in the case of artificial creativity. For example, *authenticity* refers to being faithful to the original per definition. In the case of human authenticity, this means being her or his authentic-self and expressing unique personality. Social recognition and hence the persuasiveness of the emergent creative outcome is also highlighted. Problem finding; namely the identification, definition, formulation, and construction of a problem, should be covered by the human creative process that is not inhabited by the computer, unless instructed by a human. Artificial creativity is contended to cover only some elements of the “real” creativity. AI covers for example elements of *originality* and *effectiveness*. According to this view, distinction should be made between real emergence versus mirages and hallucinations that are produced by the computer that exhibit only the appearance of creativity rather than representing true novelty and inventive productions.

Herbert Simon, a social scientist, and a leading figure in AI research from the twentieth century, agreed to the idea that creativity is attributed to products that are both novel and interesting or valuable (Simon, 2001). He was optimistic about the potential of simulating the creative act in a psychological laboratory such that, given the same conditions as to human beings, computer programs would be able to produce creative outcomes. Simon argued that the creative process was incremental where the creative person, whether a scientist or an artist, explored and experimented with rich materials that are incremented and contributed by others. Although it is admitted that creativity in arts is less researched than in the science, the underlying creative process is assumed as being similar. Moreover, Simon proposed that the human creative process exhibited in the science and art domains does not significantly differentiate from other mental activities, whether it is a problem solving activity, or a decision making or design process, which eventually result in novel, interesting and valuable outcomes.

⁶ Effective surprise is used by the psychologist Jerome Bruner to define the creative act where novelty is produced, in his writing of 1962, “The conditions of creativity”.

Boden (2009) argues that computer artists are not necessarily interested in understanding the creativity as a phenomenon but are focused on the artistic outcome. Nevertheless, algorithmic art is produced with the involvement of researchers from various backgrounds including engineers to implement the creative program. Public reaction and critique on the artist's creation eventually decides on the importance of the produced work (Nake, 2012).

Frieder Nake, himself a pioneer of computer art, argued that creativity is qualitative in nature. According to his observation, "randomness" is at times seen as the counterpart to creativity in computer art that boomed around the 1960s. The notions of "computer art", "digital art" and "algorithmic art" were used interchangeably most of the time (Nake, 2012).

While exploring the realm of computer creativity, the concept of information aesthetics and its historical evolution emerges as a crucial framework. *Information Aesthetics* was born as an interdisciplinary approach and an attempt to define rational and objective theory of aesthetics during the 1960s inspired by Claude Shannon's Information Theory in defining objective measures for aesthetics based on mathematics. The movement had two academic centers in Europe, the University of Stuttgart in Germany with Max Bense as the leading figure, and the University of Strasbourg in France with Abraham Moles. In this regard, Moles' work focused on sequences in time while exploring artificial creation of, for example music, whereas Bense concentrated in the space aspect and experimented with images and text. Frederik Nake emphasized that "Information Aesthetics" as reflected in more contemporary concepts is identified by the display of large amounts of data, whereas the "generative design" requires executing a program with complex parameter settings on a computer (Nake, 2012').

Max Bense himself described the modern aesthetics concepts that were built during the 1960s as rather abstract or mathematical, moving away from the classical subjective approach of the past (Bense, 1968). The artistic object became the carrier of an "aesthetic state" which is a state of "order" over a set of material elements of a certain "complexity". Symmetries represent "order" according to this description. Bense referred to four phases in defining the aesthetic state of an object that are classified as the numerical aesthetics, the semiotic aesthetics, the semantic aesthetics, and the generative aesthetics. *Numerical aesthetics* described the material properties

of an object that are related to frequencies, entropies, statistical information, and redundancies. The order of an object could be measured using redundancies whereas the complexity would relate to entropy and statistical information according to this approach. *Semiotic aesthetic* viewed the creative process of art from the window of an “relational sign” aesthetics. According to *semantic aesthetics*, on the other hand, the aesthetic state became the carrier of meaning where the meaning was transmitted through the signs as part of a communication schema. *Generative aesthetics* view took a step further and was targeting a clear definition of the process of producing art. A “definite” approach on the aesthetics was pursued. Ultimate goal was to generate aesthetic states by implementing and running computer programs (Bense, 1968).

Georg Nees, a pioneering figure in the visual arts, is recognized by performing the first known computer art exhibition. Several artists visited the exhibition from Stuttgart Academy of Fine Art in the opening of February 1965. During the event, Max Bense held a speech on projects of generative aesthetics and Nees continued talking about technical issues related to the design and implementation of his drawings. An artist in the audience raised a question as reported in Nake (2012, p.72): “...So tell me: will you be able to raise your computer to the point where it can simulate my personal way of painting?”. After a short moment of thinking, Nees answered: “Sure, I will be able to do this. Under one condition, however: you must first explicitly tell me how you paint.” (Nake: 2012, p.72). This dialogue adds a valuable dimension and awareness to the discussion of what authenticity might be and who possesses the creativity in art generated by a machine.

While the concept of implementing creativity through the computer's deterministic, algorithm-bound platform presents an inherent contradiction to the requirements for originality and flexibility, a notable amount of research continue in the computational creativity field triggered by a variety of motivations. Existing literature confirms to that contemporary research in computational creativity pursues comprehending how creativity works and exploring to what extend it can be replicated by the computer (Carnovalini and Rodà, 2020; Rohrmeier, 2022).

The debate about whether computers have the potential to become “really” creative, or in contrary, whether their ability is strictly dependent on the human programmer, will not be further addressed as part of this thesis. In alignment to that, assessment of the artistic value of computer-generated artwork is out of the scope. The focal area of

the study is algorithmic design of creativity within the realm of AI history. In this regard, the historical pathways traced in the programming of artistic creativity as part of the three different artistic branches; music, painting, and poetry, will be explored to investigate methodical definition of the creative process by the researchers.

3.3 Comparative Analysis Of Early Computer-based Music Composition, Painting And Poetry Algorithms

Art movements emerge as a phenomenon at the intersection of the social sciences and technology and evolve under the influence of contemporary events impacting societies, discoveries, novel ideas and paradigm shifts. While studying the historical development of making art by artificial intelligence, the blend of developments in various influencing fields including arts, mathematics and computer science and their interactions should be explored.

French Revolution of 1789 is thought to be influenced by the American Revolution of 1776 and it is accepted as a turning point in the history of humankind, bringing social change by the introduction of key ideas about freedom and individual rights. In the art scene, similarly, previously established limits were questioned from the nineteenth century expressionism to the twentieth century modernism and surrealism, pursuing diversity. Speech of freedom and new ideologies were reflected in the rule-breaking works of the artists of the era. Surrealism is claimed to have been at the heart of early computational culture. Pablo Picasso, the leading figure in painting in the twentieth century, established Cubism followed by the Surrealism that was proposed in the *Surrealist Manifesto* in 1924 by the French-German poet Yvan Goll together with the French poet André Breton. The movement evolved in resistance to the conformist approaches of their time. Surrealism showed a way to the unconscious mind, dreams, imagination, and virtuality. They were eventually connecting to the mind's neural networks and artificial intelligence. Major developments in the computer science in 1950s, including Claude Shannon's information theory and Alan Turing's machine intelligence, introduced artificial intelligence into our lives with no turning back. The invention of *World Wide Web* by Tim Berners-Lee in 1989 further fostered digital convergence of cultures and productions in arts and technology (Giannini and Bowen, 2024).

Alan Turing drafted a report on Intelligence Machinery in 1948. He argued under the section named “Intelligence as an emotional concept” that our own state of mind and training by the concerned object’s properties would be key in referring something as behaving intelligent: “The extent to which we regard something as behaving in an intelligent manner is determined as much by our own state of mind and training as by the properties of the object under consideration.” (as quoted in Giannini and Bowen: 2024, p.101; Turing: 1948, p.19). In the earlier section of the report, Turing highlighted three types of searching that were classified as intellectual, genetical and cultural. Turing added that the cultural type of search cannot be developed in an isolated environment but within a human community. Computer science, mathematics, and the arts are together centered around emotional intelligence and creativity. The creative practitioners who are operating within collaborative communities are frequently driven by internal personal emotional depth, a motivation that defined artistic movements from impressionism through modernism to contemporary practice. The artists navigate a complex cultural search from their individual psychological expression to the broader societal discourse (Giannini and Bowen, 2024).

Computer generated arts were initiated with the emergence of mainframe computers in the 1950s. Mainframe computers provided the required platform to combine signs according to programmed rules and produce texts during the middle of the century. Pioneers of computer arts were partially influenced by cybernetics, while some directly worked on developing cybernetic methods. Cybernetics and computer technology met during the Second World War for the first time in research for anti-aircraft technology in the United States. Cybernetic methods were initially utilized in applying mathematics for technical problems and progressed into a generalizing science over the time. The concepts of information aesthetics based on cybernetics became widespread and inspired computer-generated art experiments from 1960s throughout 70s, throughout the twentieth century (Dreher, 2020).

3.3.1 Music composition by computer

In the realm of automated arts, music making dates to much earlier than the emergence of universal computer. One of the earliest automatic musical instruments was a wind instrument designed by Appolonius of Perga (247-205 BC), according to the existing historical reports. In the thirteenth century, Dutch musical engineers designed binary

programmable carillons with up to ten thousand memory locations. Later, the eighteenth-century society was fascinated by the music playing automata, especially with the machines introduced by Jacquet-Droz in Europe. Music boxes that were constructed by punched metal-disk technology mostly emerged during the nineteenth century and evolved into the automated orchestra; the orchestrion. The invention of the electric phonograph and the microphone subsequently in the nineteenth century enabled the storage of the sound. The twentieth century marked the transition from the mechanical age to the electronic age, while electromechanical techniques were introduced to store and reproduce recorded music (Roads, 1980).

Computer music can relate to music played by or, moreover, composed by the machine. The former is done by converting scores into electronic sound and does not necessarily address composition that involves note selection (Hiller, 1981). Music composition is the creative area of computer music that this thesis will focus after providing a brief view on the history of AI related music making.

Music has been acknowledged as a field where the available technology in a certain time period has always been utilized at most. Computer music started as soon as the universal machines entered the scene. Nevertheless, automatic computers as the first programmable electronic computers were initially constructed with the fundamental purpose of coping with the challenges in complex mathematical calculations required of humans, whereas the music making using the computer was not an ordinary idea. Early machines were rather producing raw sound. Some of them possessed a loudspeaker unit that was used by the programmer or maintenance engineer to communicate with the computer; for example, certain sound output indicated termination of the program during the execution, or a signal was used as diagnostic aid for the users (Doornbusch, 2017).

There were various experiments conducted with the algorithmic music composition starting from the mid-century period of the twentieth century, however some of them were distinguishable from others. The composer Lejaren Hiller together with the mathematician Leonard Isaacson started working on the *Illiac Suite for String Quartet* that was completed in November 1956. The quartet is known as the first algorithmic music composition written by the extensive use of a digital computer. The piece was published with eighteen minutes duration. The Illinois Automatic Computer I (hereafter ILLIAC) at the University of Illinois at Urbana-Champaign was used to

generate the composition. Nevertheless, it is reported that on 15 July 1956, a piece that was programmed by Douglas Bolitho and Martin L. Klein and called *Push Button Bertha*, became public on the television program *Adventure Tomorrow*, less than a month before the 9 August 1956 performance of an incomplete version of the *Illiac Suite* at the University of Illinois by Hiller and Isaacson (Ariza, 2011; Hiller, 1981).

Ariza (2011) reports about two pioneering projects in the history of computer aided algorithmic composition (hereafter CAAC); the work of David Caplin and Dietrich Prinz in 1955 that introduced new musical structures, and the work of Harriett Padberg in the early 1960s as one of the earliest academic works in CAAC, especially published by a woman. Both experiments were demonstration of applying new techniques on different historical music.

Caplin and Prinz implemented formerly defined procedural approaches based on the dice games attributed to Mozart. They also experimented with conditional probabilities to generate melodic lines. Their initial experiments with the computer aided algorithmic composition date back to 1955. These were documented and shared with Lejaren Hiller in a letter in 1960 by Caplin. The implementation of Mozart's *Musikalisches Würfelspiel* by the computer employed both basic synthesis technique and a random number generator. Caplin and Prinz utilized *Ferranti Mark I* computer in their early experiments and the more powerful machine *Ferranti Mercury* later in 1959 (Ariza, 2011).

Harriet Padberg is known as another pioneering researcher in the early computer music experiments. She designed a system based on Guido of Arezzo's pitch-to-vowel mapping technique. The PhD dissertation of 1964, the "Computer-Composed Canon and Free Fugue", provides detailed documentation of her computer-based system for algorithmically generating canons and the so-called free fugues. The published research covered implementation details and the entire FORTRAN language code as well as score tables of complete compositions. Padberg, as quoted in Ariza (2011, p. 48), did not aim to produce a masterpiece using computer: "...it is evident that no exclusive use of mechanical devices, no matter how logical these may be, is sufficient to produce a masterpiece in any medium". She was concerned with better understanding the process of music composition:

It is in the hope of furthering this search into the structural properties of music that the present work is undertaken. By the correlation in a computer-program of a scale of frequencies, of melody and rhythm derived from the relationships inherent in a meaningful phrase or sentence, and of a form capable of being transformed and developed by logical techniques, a basis for further composition in the contemporary style is suggested as well as the means for a better understanding of the process of musical composition. (Padberg:1964, p. 23)

Later in the 1960s, two important research papers were published on AI and music; the "Pattern in Music" by Herbert Simon and Richard Sumner at Carnegie-Mellon University, and "Linguistics and the Computer Analysis of Tonal Harmony" by Terry Winograd then at Massachusetts Institute of Technology, according to Roads (1980). The popular Markov-chain model that was used in the early years of music composition was questioned by A. W. Slawson in consideration whether Naom Chomsky's work on grammars a better generative model for music could be. The focus of algorithmic composition remained as achieving aesthetically satisfying new composition, whereas generative modelling of music included proposing and verifying a theory that generated them. The purpose of the "Pattern in Music" was to formalize musical patterns in tonal music into a language that could be used by a computer program for translating descriptions into musical notations and automatically inducing patterns from scores. Cognitive activity of music listener was explored by the program while describing the pattern for music composition. Winogard's harmony-analysis program on the other hand was aiming chord labelling based on systemic grammar model that was developed in the 1960s to make a choice from options based on an entry condition. The model was designed to encode semantic options, with grammatical options serving as their eventual realizations. The program developed by Winogard utilized semantic procedures to parse the music. By the middle of 1970s, automatic recognition of music was explored by the researchers in the field. Information processing psychology and generative grammar models proposed by the particular researchers A. Newell, H. Simon, G. Miller and N. Chomsky, were utilized in developing the theoretical framework at the Institute of Sonology in Utrecht. Knowledge-based understanding became essential later in the problem-solving part of

an intelligent music recognition system; also called a musical robot, that additionally contained a pattern-recognition part and a grammar defined for music (Roads, 1980).

The composer Lejaren Hiller, in the progress report of 1981, outlined important issues about composing with the computers. Accordingly, computer-assisted composition is hard to define, limit and systematize, and music composition should be considered as a process where the composer is required being aware of the logic behind the creative act and should consider compositional priorities (Hiller, 1981). In alignment to that, the computer as a composing machine is equipped with algorithms to generate scores based on the initial input data, that can be enriched by running sound synthesis algorithms together with natural sound input that are converted from analog to digital, and further by adding input from the composer's own scores. The output is directed to a digital to analog converter which subsequently can be played back on an audio tape recorder. While Hiller defines his approach to computer composition, he first mentions pragmatic concerns; that is the music in the end should be performable and the performance would be a test of the outcome. A notable feature of the approach is its emphasis on probability and statistics. His music, as Hiller describes, tends to proceed from dis-order to order. The process is initiated with random generation of musical elements and is being progressed by the application of increased number of constraints on the elements' acceptability. He admits the influence of information theory on his own approach. To preserve the creativeness in the music composition process, Hiller suggests avoiding the use of deterministic algorithms based on mere data transformation (Hiller, 1981).

Hiller's report further provides an idea about what kind of algorithms are running behind the music samples composed with computers in the years following the production of the Illiac Suite for String Quartet (Hiller, 1981). Accordingly, the basic problem solving with an emphasis on statistics and stochastic processes are employed for the Computer Cantata of 1963. The composition HPSCHD piece of 1968 was made of three sets of computer programs; a computer program for composing and producing sound by means of digital-to-analog conversion, another one for composing harpsichord pieces that are derived from Mozart's Musical Dice Game⁷, and a final

⁷ "A Musikalisches Würfelspiel (German for "musical dice game") was a system for using dice to randomly generate music from precomposed options. These games were quite popular throughout

third program for creating a performance part that was prepared for a commercial phonograph recording by the human composers. The basic note generator that was utilized for the composition was a subroutine in the name of ICHING⁸ that recreated the *Oracle of the Book of Changes* and generated products based on a polynomial distribution. The emphasis of employing stochastic models is clearly observed by these examples provided by Hiller (1981), in the early years of music composition by the computer. The “random” element was used for experimenting with creativity using the machine.

Illic is known to be pioneering in music composition by computer, although not being the initial experiment and music piece realized by the computer. The roots of modern computing stem from the 1940s with the earliest recognized machine as a computer being the Small-Scale Experimental Machine (hereafter SSEM) at the Victoria University of Manchester as argued by Doornbusch (2017). The design was improved and commercialized as a general-purpose computer Ferranti Mark 1. Alan Turing provided the researcher Christopher Strachey with a programming manual of the machine, and he finished coding a program to play draughts in October 1951, where at the end of the program, the British national anthem “God Save the Queen” was played by machine. The channel BBC recorded this event as the first recording of a computer playing music. Similar attempts were noted in Australia in the early years of computer in playing music with the computer, however they were rather seen as amusement, and researchers were interested rather in the calculating capabilities of the machine. The developments in computer music was there not scientifically valued as much as in the United States where research in the field was further supported for future developments. The Bell Telephone Laboratories initiated a project with the purpose of exploring computer music and a composer joined the team with the researchers (Doornbusch, 2017). Notably, the music played by Ferranti Mark 1 was

Western Europe in the 18th century. Several different games were devised, some that did not require dice, but merely choosing a random number.” (Wikipedia, retrieved in October 2024)

⁸ “The I Ching or Yijing (Chinese: 易經, Mandarin: [î teín]), usually translated Book of Changes or Classic of Changes, is an ancient Chinese divination text that is among the oldest of the Chinese classics. ... As a divination text, the I Ching is used for a Chinese form of cleromancy known as I Ching divination in which bundles of yarrow stalks are manipulated to produce sets of six apparently random numbers ranging from 6 to 9. Each of the 64 possible sets corresponds to a hexagram, which can be looked up in the I Ching.” (Wikipedia, retrieved in October 2024)

not produced as an autonomous music generation, it was a synthesis and performance based on existing music. In that sense, corresponding creative element was debatable.

Further developments were noted from the 1960s in the field of computer music as reported by Verma (2021). In 1960, the Russian scientist R. Kh. Zaripov published one of the earliest academic papers on algorithmic music with the title of “An algorithmic description of a process of musical composition”. URAL-1 computer was used in his research. Ray Kurzweil, in 1965, demonstrated a computer created piano piece. The American researcher used a program that was capable of recognizing patterns in musical compositions, analyze and re-used them in generating new music pieces. In the beginning of 1970s, Experimental Music Studio (hereafter EMS) was established by Professor Barry Vercoe at the university of MIT to dedicate research on computer music. Real-time digital synthesis, live keyboard input, graphical score editing, programming languages for music composition and synthesis were focal areas of research. The paper “Machine perception of musical rhythm” was also published at EMS in 1975 and an intelligent music perception system was developed to automatically recognize and record meter, tempo and note duration during the live performance of a musician. A breakthrough in computer-based music research emerged in 1980 by David Cope at the University of California, Santa Cruz when they developed “Experiments in Musical Intelligence” (hereafter EMI). This work was groundbreaking by shifting away from giving the computer a list of rules and introducing the composer’s style to the computer to analyze and emulate. The EMI utilized corpus-based methodology and augmented transition networks adapted from natural language processing. The system was fragmenting existing music and recombining pieces thereby creating novel music of the original style (Chen, 2024; Verma, 2021; Wang, 2024).

Hiller and Isaacson published the book “Experimental Music: Composition with an Electronic Computer” in 1959 as an outcome of their research with algorithmic composition. A book review of the same year by Peter Westergaard suggests about the method used in the experiments performed by the composers with the electronic computer. The characteristics of sound such as pitch, timbre, dynamics, and rhythm are represented as numbers whereas the relationships between them such as interval for the pitch as arithmetic operations. The laws that are assumed to govern specific kind of music are formulized into operating instructions that can be run by the machine

using the characteristics as numbers and the relationships as operations. Various governing laws involving restrictions were applied in the different experiments to obtain the desired music. In the initial movements, the restrictions of first species counterpoint were applied. The third experiment focused on timbres, dynamics and rhythmic patterns yet included governing law of preventing two successive skips for melody and proper resolution of tritones for harmony. The fourth experiment was based on Markoff chain where the likelihood of each successive note in a line was impacted by weighted probabilities assigned to the interval between that note and another. The other note usually became the preceding note or the first note of the corresponding section. Eventually, the Monte Carlo method was used to produce the music by the help of the governing laws. A set of random numbers were generated by the computer and operating instructions helped to decide on the characteristics in alignment with the governing laws to record compatible numbers into an output tape that were then decoded into music. The experimenting researchers who were at the same time the authors of the book highlighted that their initiative was not meant to be an artwork but laboratory research. It is assumed according to the review, that the limitations of computer composing stemmed from the limitations of us as human in understanding and dissolving the music composition process, rather than the technical limitations of the machine. Researchers in the field of computer music were hypothesizing about the governing laws and the computer as a laboratory platform provided a reliable way of checking whether these were accurate (Westergaard, 1959). Hiller and Isaacson (1959) explained the paradigm shift toward an experimental scientific methodology in music composition that was maintained by integrating computing into musical analysis, as it was exemplified by the application of the Monte Carlo method in the Illiac Suite. By quantifying musical structures as numerical data, researchers were able to utilize the computer as a controlled, unbiased laboratory for composition. This process allowed investigators to formulate certain hypotheses regarding musical theory, translate them into algorithmic principles, and evaluate the resulting output to refine their initial theories. Ultimately, the computer served as a vital instrument for testing the validity of analytical concepts within an isolated and objective environment, bridging the gap between traditional musicology and formal scientific research.

Initial attempts of computer based music composition resembled a scientific experiment with less emphasis on the esthetics concerns (Westergaard, 1959). The aesthetic problem in music nevertheless was addressed by Hiller and Isaacson (1959), by highlighting the essence of music communication as well as the mental and technical process of music creation as main problems of music discussions throughout the history. It is argued that music has less tangible reference models in nature where meaning and coherence in the field results through more formal procedures than other fields of arts such as in the graphic or literary arts. Early philosophers and mathematicians considered music as a form of mathematics while they believed that law of nature was expressed by music using mathematical logic.

Communication and information theory inspired researchers in the field from the beginning. The paper “Information Theory And Melody”, a mid-twentieth century publication of the Scientific American, illustrates this connection (Pinkerton, 1956). Accordingly, entropy is the key concept that describes the association between the elements of a system and eventually applies to the notes in a music composition. It can be considered as a numerical index of the disorder in the system that increases with the degree of uncertainty, that on the other hand, decreases with order such as in the form of organized patterns and symmetry. The size of the information to be conveyed in a message, increase with a higher level of entropy. Familiarities in a system mean repeated information, hence, redundancy. In a system of regularity and symmetry, size of the information and entropy would be reduced. Reflecting into the field of music, a melody with basic regularities and symmetry would involve somewhat redundancy that would help identifying patterns, however the piece should carry sufficiently high degree of entropy to be complex and interesting enough. Researchers exploring with music assumed that features of music such as melody, rhythm, and harmony can be formalized into a statistical scheme that would lead to building machines for creating music in future. New styles of music of any type could be created by alternating probabilities. Experiment showed that the entropy, in other words the average information per note, could be calculated which in return provides the amount of information or expressible meaning that can be contained by certain melodies. Quantifiable amount of redundancy or repetition is required for achieving tuneful melodies. Rhythm ensures periodic properties that can be represented in a mathematical or mechanical way. Resulting model makes it possible to build machines

which are capable of making music by involving desired degree of entropy, redundancy, and periodicity. Early scientific experiments provided optimistic results to assume that random choices could be in future made by the computer between melodies to select less banal music pieces among the outcomes. Information theory hence is expected to play an important role for studying the creative process of human mind and understanding features of creativeness (Pinkerton, 1956).

According to Hiller and Isaacson (1959), music; like language, was considered as a discrete communication system where basic texture of it could most of the time be defined with a set of discrete symbols except for some electronic music forms. Meaningfulness of a message can be increased by restricting the number of choices as per the information theory. In the most diffuse type of music, successive note selection can be easily randomized by computer to form basic substance that can be then customized to possess more characteristics structures. Statistical methods can help to compute transition probabilities between the notes to select succeeding notes according to known music samples and generate new music piece. The logic behind the music composition process was described in terms of five basic principles. According to the first principle, music is identified as a systematic ordering process that transitions from a state of chaos to a structured arrangement of selected elements. Secondly, the degree of imposed order ranging from total entropy to rigid structure is a fundamental variable in defining musical form. Third principle highlights the pitch and time as most important dimensions of music to impose order, while parameters like timbre and dynamics are treated as auxiliary. Fourth principle necessitates memory and immediate perception for musical comprehension. Finally, tonality is redefined as a dynamic result of pitch organization mediated by the listener's ability to recall memory and relate previous auditory data (Hiller and Isaacson, 1959).

The process of experimental music composing required taking into consideration the described logical principles. A process of elimination was defined to select musical materials out of a random environment. Restrictions imposed during the process of elimination determined the range of order. The main dimension of music organization was the pitch (intervals between notes) and the time. Traditional rules of composition were used to express interactions between them. Musical coherence in a musical structure is achieved by both utilizing memory and immediate sense perception. Hiller and Isaacson recognized that setting up the proper articulation in a music structure

would work according to this principle. They also referred to Abraham Moles' studies about information theory and aesthetic perception of music. The perception, also called the attention to retrieve messages out of sounds, is considered in terms of semantic and aesthetic modes of music. Semantic mode, like language, is organized in a set of standardized symbols that are eventually coded, in other words translated into another language, into the score. Aesthetic mode might not be intellectually grasped but appeal to the directly sensorial abilities at a certain limit. The term "acoustical quanta" was defined by Moles (as cited in Hiller and Isaacson:1959, p.30) to refer to the repertory of aesthetic symbols at a given temporal scale and information delivery velocity that eventually, when computed, approaches to the semantic information rate. As a result, semantic and aesthetic information in music is aligned with similar acoustical sets of quanta although captured by other means.

Around the 1950s, non-numerical use of computers, that is for purposes other than arithmetic operations like for business or any other operations of interest, was a rather novel idea. Generation of computer music fell under that category of non-numerical application of computerized experiment. Although the meaning of creativity was debatable like the meaning of intelligence or thinking, it was expected that a computer could self-sustain operation and learn from experience to act creatively. It was accepted that the early computers should not be expected to generate new music principles, whereas these had to be pre-defined to the machine in explicit detail. The uncertainty and hence unpredictability could be mainly introduced by the usage of randomization to provide freedom of choice, which was hardly sufficient to qualify the process as creative (Hiller and Isaacson, 1959).

To summarize, the composers who were experimenting with algorithmic music first used computer as a kind of a laboratory to run and refine their model of formalized composition process which was built after their perception of music composition. Their main aim was not necessarily to generate creative value in the field of music with the computer, rather than that, researchers were trying to analyze and understand how human composers methodically compose a music piece. The computer provided a platform to run algorithms designed based on the human-like composing process and to verify and improve them continuously based on the music composition produced by the computer. Hiller did not claim to produce an outcome of aesthetic value. There was not an aspiration in place about making arts with the computer, yet. The initial pieces

did not necessarily sound like human-composed music, and it was not easy to play the scores produced by the computer by a human musician. They were unusual. From Turing's Imitation Game perspective, the intelligence of the computer composer was doubtable. However, these issues were not concerned by the pioneering researchers in the algorithmic composition field. They positioned the computer as a playground and a laboratory to analyze, model, test and improve their understanding of the creative music composition process.

The methodologies dominantly employed in computational music generation until contemporary times are organized into various core paradigms ranging from stochastic models like Markov chains, frameworks of formal grammars, heuristic rule-based systems, genetic algorithms to more recently applied Neural Networks and Deep Learning, alternative Chaos theory based models to self-similarity systems and agents based systems (Carnovalini and Rodà, 2020). This research illustrated Markov chains, frameworks of formal grammars and the rule-based systems as dominant methods used in the twentieth century experiments. Artificial neural network-based music generation emerged in the late 1980s. The development of deep learning techniques influenced over the time computer music generation similar to other creative work domains. Critic exists however, due to the black box nature of systems working based on machine learning, it is hard to evaluate the underlying functioning of the generation process and the usage of dataset and ultimately to control the piece produced by the system. Genetic algorithms employ a combination of solutions to generate new ones based on a random set of initial solutions and work by selecting better fitting answers to evolve into the optimal solution to the original problem. Specification of a problem remains a challenge, however, genetic algorithms have been used in the implementation of music generation systems, with well-known examples dating to the 1990s. It is noted that these methods are used in a hybrid way, for example by using Markov chains in generating initial population, evolving grammar rules or parameters of a Markov chain and incorporating neural networks or human assessments in the fitness function for the genetic algorithm. Self-similar systems, on the other hand, have been used to generate musical material which serve as inspiration to human composers. This is mainly possible due to the nature of music compositions containing certain degree of repeating patterns and variations in the musical structure and spectral density. It is emphasized that these systems are based on chaotic and random decision making processes and

due to lack of their aesthetic value are less interesting to AI practitioners. Nevertheless, they provide means to explore unconventional melodies. Ultimately, agent based systems provide a modern approach and a meta technique rather than a specific algorithm for music generation. The agents, autonomous software with perception and action abilities, can cooperate and act as part of a multiagent systems. Various autonomous agents in a system generate improvised melodies according to an algorithm while production is being regulated according to a behavior model maintaining a general agreement between the agents (Carnovalini and Rodà, 2020).

Technological advancements and novel AI techniques as applied to various field of research contributed to the sophistication of computer based music generation simultaneously. Machine learning, in particular deep learning models such as Generative Adversarial Networks (hereafter GANs) and Recurrent Neural Networks (hereafter RNNs) play an important role in the contemporary implementations. Using computer-based methods provides advantages in the speed and scalability of composition and supports the composer in experimenting with unfamiliar elements introduced by AI. Furthermore, easy access to tools and methods, and the cost efficiency of their usage make automated music composition attractive for the producers. Eventually, the use of AI in the creative industry is impacting music production processes and the overall experience of the audience (RaNa, 2025).

In a recent study, it is argued that music creation requires general artificial intelligence capabilities making it an AI-complete problem (Rohrmeier, 2022). This is based on the inference that music making requires a cognitive model of music as it exists within the human mental sphere. The cognition furthermore depends on the biology of the body. Accordingly, models of body, instrument and settings impact the overall composition process. Music creation requires also non-musical references in the external world, for example a model for inhabiting the sound and motion dynamics of external world objects. In addition to these, musical artificial creativity contains the meta-creativity challenge. This involves higher order concepts in musical composition techniques and forms such as Mozart's creative composition idea using the musical dice game. Applications of musical quotations and allusions as triggered by semantic or pragmatic purposes fall within the complexities inherent in the generation of music by the AI.

3.3.2 Digital visual arts

Information aesthetics, an attempt to define rational and objective theory of aesthetics during the 1960s, was concerned with the relations between the structure, the complexity of a visual information and the orderliness in the visual perception of its presentation. As Dreher (2020) explains, Max Bense and Abraham Moles defined the “aesthetic measure” by examining this relationship in different ways: Bense used George David Birkhoff’s definition and proposed “order divided by complexity”. On the contrary, Moles suggested “multiplication order by complexity” as measure. Accordingly, Bense was proposing the elimination of redundancy while formalizing aesthetics. Moles was on the other hand focusing on the observer’s perception and the limits of apperception where it was assumed that certain level of redundancy was required for the recognition of order. The numerical definition of “aesthetic measure” was built on Shannon’s “statistic information”. The approach worked based on that the number of used elements, “sign repertoire”, and the possibilities to combine them were precisely given. Information theory provided an objective way for achieving the aesthetic goal through the definition of the relationship between information and redundancy. Algorithmic art offered a way to implement information aesthetics as a result (Dreher, 2020).

Max Bense worked on information aesthetics starting from the 1950s under the influence of theories from various scientific disciplines. Bense considered the aesthetic object as a sign and positioned that within Shannon’s communication theory while adapting it within the realm of human communication. Norbert Wiener’s cybernetics and Noam Chomsky’s generative grammar further influenced Bense in building a theory for rationally defining aesthetics based on scientific theories. All these developments led to the formation of the Stuttgart school in the 1960s with Bense as the leading figure. In synthetically produced aesthetics, it was aimed to produce “order” based on certain rules. Considering art as a ratio between disorder and order where the tendency is from disorder to order, the element of disorder was involved by randomization defined in concrete generative computer programs. That was a change of mind in the production of aesthetic objects. The relation between intuition, chance and pseudo-number generators was of interest to the graphic artists of the time. Frieder Nake, the computer artist and an import figure from the early years of digital arts, was revolutionizing the act of making art into a scientific experimentation, moving away

from the principle of "trial and error", an old approach followed by the traditional artists. Humanities and science as two separate fields of research were eventually converging during the production of computer art (Klüttsch, 2007).

According to Nake (2019), computer art; in other words, algorithmic or generative art, caused a paradigm shift in making the art “work” by the introduction of computer, similar to the impact of preceding machines in the history which changed the way of human working. Computer artists, after this change in the act of making art, were expected to focus on “thinking their work” rather than “making it”. This also triggered a change towards defining a way for endless production of artwork for the masses in opposition to creating single masterpieces. Individual objects were no longer independent but belonging to an infinite class of works where singularity or the individual differences could be achieved by altering parameters within a set of permitted values. Not only specific to arts, but in general, the advent of the computer mechanized⁹ mental labour just as the machines that emerged before in the history served mechanization of industrial labour. The computer as a semiotic machine was seen as a tool at first place and then became a medium. Marshall McLuhan's publication of “Understanding Media” of 1964 contains the slogan “The medium is the message” and McLuhan claims that “the 'content' of any medium is always another medium” as quoted in Nake (2019, p.44-45). The initiation of the computational process transforms a passive storage medium into an operating entity. The operating machine reads and interprets stored symbolic data and turns itself into a special purpose computer generating lines and marks on paper, manifesting a physical translation of the digital instructions into a different material medium.

The artistic use of the output of cathode-ray oscillographs is counted as part of the prehistory of the overall narrative of computer graphics. Benjamin Francis Laposky photographed the screen of his oscillograph since 1950, and thereby established a connection with computer art by relating the oscillations to analog curves in the analog computer systems (Dreher, 2020).

⁹ Nake(2019) uses the “machinization” instead of “mechanization” by considering the computer as the instrument for transforming mental labor into machinic operation, which eventually is not a mechanic machine.

In the early years of visual computer art, in the 1960s, the mathematical object polygon played an important role in the production of digital artifacts. Random polygon drawings made by computer algorithms transformed invisible geometric objects into visible graphics and created digital art. During this period, three scientists emerged who had access to computers and who, without knowing each other, began experimenting with computer art production by writing algorithms and simple drawings. Georg Nees and Frieder Nake in Stuttgart, Germany, and Michael Noll in New York, the USA, they all presented their works of art to the public in 1965. One of first publications of digital visual art was produced during Nees' exhibition event in the form of a booklet as part of the "rot 19" edition. The 1965 publication of the booklet rot 19, contained Max Bense's important essay *Projekte generativer Ästhetik*. The article introduced the term "generative aesthetics", explicitly derived from Noam Chomsky's generative grammar concept which was suggesting the production of aesthetic structures through a set of algorithmic rules similar to linguistic syntax. The publication served included reproductions of Georg Nees' pioneering computer graphics and technical explanations of their underlying code (Nake, 2012).

The "rot series" or "Edition Rot", was an experimental publication that was initiated in the 1960s by Max Bense, the leader of Information Aesthetics movement at the Stuttgart School, together with Elisabeth Walther, his wife. The series provided a platform for bringing interdisciplinary developments of the period to the public eye. These covered progress with regards to concrete poetry, semiotics, and cybernetics amongst others. The nineteenth issue of rot, that was published in 1965, was notable for addressing generative aesthetics given Max Bense's statement and covering Georg Nees' computer drawings that are considered among the first programmed artistic images which became publicly available to larger audience ever (Robillard and Lioret, 2019).

Initial "explorers" of digital visual art utilized computer as a technical machine that was able to generate drawings. The machine's capability of "being creative" was limited. Computer artists used mathematics and challenged the machine to generate more complex shapes beyond drawing simple straight lines. The English translation of George Nees' pseudo-code as quoted in Nake (2012) illustrates the corresponding algorithm designed for the generation of polygons for generating visual art:

Start anywhere inside the figure's given square format, and draw a polygon of 23 straight line segments. Alternate between horizontal and vertical lines of random lengths. Horizontally go either left or right (choose at random), vertically go up or down (also random choice). To finish, connect start and end points by an oblique straight line." (p.69)

Nake (2012) explained the value of the oblique line aberrating surprisingly from the standard geometry of the polygons and hence adding to the aesthetic quality of the resulting image. The simple composition of geometrical elements leads to aesthetic quality according to this approach. Random choices during the drawing are handled by the execution of the underlying computer program. However, computer cannot act random; every single next step must be precisely defined, in other words, be computable. This was ensured by utilizing mathematics; for example, by using probability distribution functions, in the early years of algorithmic art.

Michael Noll, a pioneering figure in early digital art with an engineering background, used FORTRAN as a programming language on an IBM 7090 of the Bell Labs to program "Patterns" in 1962 that contained instructions for the microfilm plotter to start further "subroutines". The computer code was producing lines of various length by connecting points given by a *White Noise Generator* that eventually formed a jagged line when combined. In the initial three versions, the point clouds were located around a central point whereas in the "Pattern Four" and "Pattern Five", random procedures for x- and y-axes calculated the points and repeated alternately to generate and make the lines horizontal and vertical. Ultimately, the line that connects all points changed its direction at right angles (Dreher, 2020).

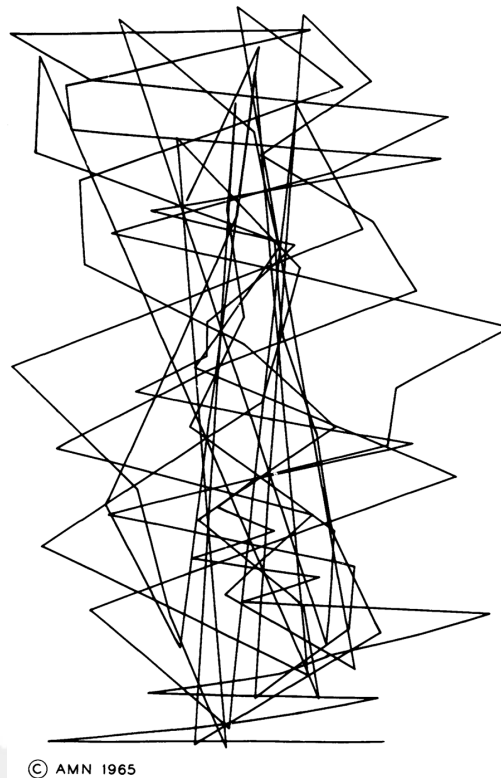


Figure 3.15 : A. Michael Noll: Gaussian-Quadratic, 1965 adapted from (Nake: 2012, p. 68).

Noll used Gaussian distribution in the horizontal dimension and quadratically increasing deterministic coordinates in the vertical while generating polygons using the computer and thereby producing the piece “Gaussian Quadratic”. According to Nake (2012), this was visualization of a quite basic mathematical process. He explored a line’s accidental direction changes in the “Gaussian Quadratic” as he did in the “Patterns” and moreover enhanced the algorithmic criteria in the line configuration of the relations between order and chance for the perception of higher level of aesthetic measure (Dreher, 2020).

Nake followed similar algorithmic principle like Noll in the “Patterns” and designed the “polygon moves” that was instructed to repeatedly selecting an x- and y-coordinate, applying certain distribution function to define target position and connecting the points continuously by a straight line. The artist provided functional parameters for the algorithm. Frieder Nake used the translation program Compart ER 56, that he developed in the machine language to control the drawing board Zuse Z64 Graphomat via mainframe computer, to create “random polygon moves”. That program used a pseudo random generator to locate points that were eventually connected with lines. Nake’s implementation was completed before Georg Nees’

programming of similar line combinations and after Noll's "polygon moves" (Dreher, 2020; Nake, 2012).

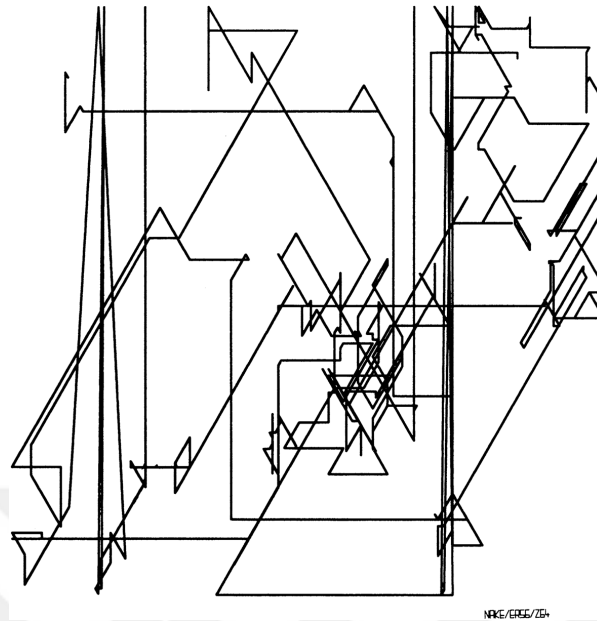


Figure 3.16 : Frieder Nake: Random Polygon, 1965 adapted from (Nake: 2012, p. 69).

The polygon moves were programmed by Georg Nees using ALGOL and published in issue 3/4 of the "Grundlagenstudien aus Kybernetik und Geisteswissenschaft"¹⁰ in December 1964. These drawings demonstrated that visual complexity could be generated by algorithmic simplicity. The polygon moves are repeated several times in the horizontal and vertical directions where the algorithm is re-executed from the start in the respective matrices with a random generator determining the distribution of consecutive lines. The program determines the number of lines. The division in matrices and the superimpositions of line configurations represents the generation of complexity by plurality and the structuring process of the perception the simplicity in Nees' works. In this regard, his graphics provided a field to explore about the achievement of aesthetic measure by moving between order and complexity (Dreher, 2020; Nake, 2012).

¹⁰ Title in German with English translation as "Basic Studies in Cybernetics and Humanities"

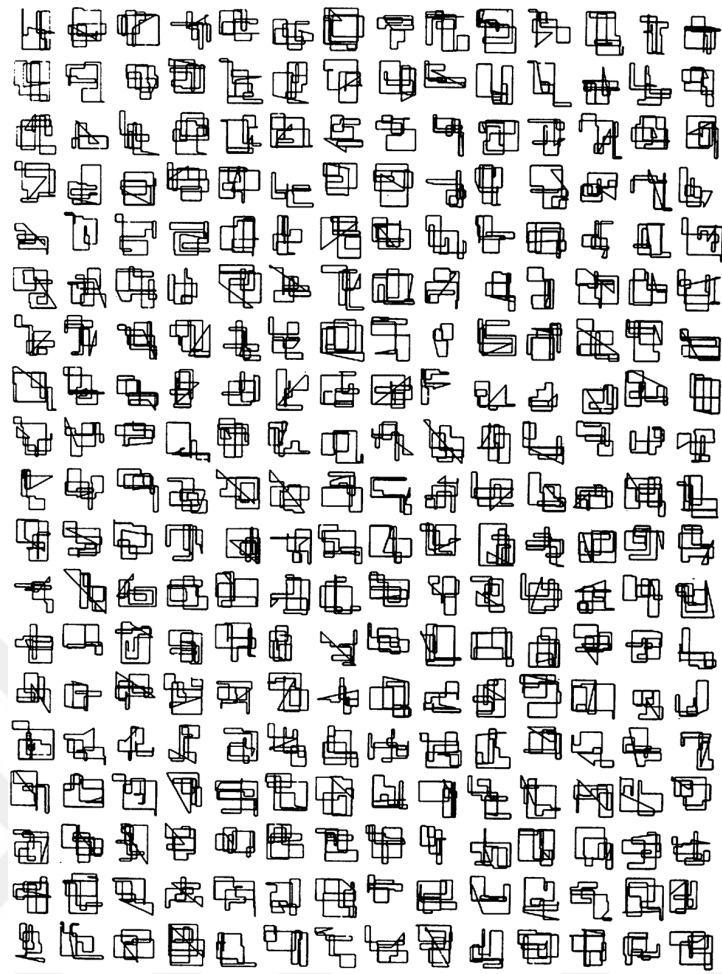


Figure 3.17 : Georg Nees: 23-Ecke, 1965 adapted from (Nake: 2012, p. 67).

Vera Molnar, a female painter from the twentieth century, was working on concrete and constructive art already for several years when she was trying to induce randomness into her graphic works. She realized that real randomness was not a straightforward ability to achieve, not by human beings as they hardly can avoid repetitions, patterns and similar. A machine was needed to bring in the desired randomness. She finally gained access to a digital computer in 1968 at the Research Centre of the computer manufacturer, Bull. Molnar precisely described the computer what to do instead of performing the work herself. Rules of behavior were strictly formulated, at the same time, certain randomness was involved by an algorithm (Nake, 2012).

In 1975, an article was published about aesthetic guidelines for computer painting by Molnar where she explained how non-figurative pictures were generated by the altering of initial simple geometrical elements and their combinations according to a

procedure (Molnar, 1975). The computer program referred to several selected parameters for the drawing of a specific image. The variation to be applied including the amount to alter at each step was given as input as part of an instruction. Alternatively, parameter changes could be made manually by the human painter in a more conversational fashion.

The modification of selected parameter values enabled the production of numerous different drawings by the computer. Sample set of parameters subject to alteration were listed by Molnar (1975):

(1) the number of sets, (2) the number of concentric squares within a set, (3) the displacement of individual squares, (4) the deformation of squares by changing angles and lengths of sides, (5) the elimination of lines or entire figures and (6) the replacement of straight lines by segments of circles, parabolas, hyperbolas and sine curves” (p.188).

Charles Csuri is recognized among the artists who pioneered use of computer for his artwork. His “Sine Curve Man” work of 1967 was innovative and revolutionary as it was a figurative portrait drawing produced by the help of computer. The program to draw this piece used deterministic rather than probabilistic mathematical techniques and the outcome was quite different than the other computer graphics of the time consisting of more precise geometric figures (Nake, 2012).



Figure 3.18 : Charles Csuri: Sine Curve Man, 1967 adapted from (Nake: 2012, p. 78).

Max Bense’s theory on aesthetics in the 1960s influenced many avant-garde artists including Manfred Mohr who valued precision and rationality in his algorithmic art.

The magic that he introduced was about that simple elements had the potential to contribute generating the most complex visual outcomes. This was made possible by the algorithmic description of the generative processes. Mohr decided to explore the *cube* as the external source of inspiration for his works in 1973 to generate aesthetic objects and processes. He worked on mental objects that are hard to visualize, specifically on three and more dimensional cubes. Cubes were instrumental in his drawings although not the subject matter. He produced algorithmic concrete images being inspired by those higher dimensions of the cubes. Those images became visible through the use of the algorithmic drawings (Nake, 2012).

The artist Harold Cohen's AARON program, that has begun development in the 1973, is prominently featured in the subsequent history of computer-generated visual arts. AARON was a rule-based gigantic expert system that was designed as a collection of interacting rules, each consisting of a condition and an action pair. In a computer program, the rule-based structure can be formalized in the form of “if C(ondition) then A(ction)” statements. An action is performed when a condition is met on some variables. The condition must be evaluated as true or false. Conditioned action is executed based on true value. The condition describes an event that varies based on the state (value) of the variables. AARON was developed by Cohen over many years and during that process a large collection of drawings emerged. Initially starting with black and white drawings, Cohen hand-colored them in later productions according to his own taste or codes determined by AARON. Cohen’s computer program’s drawings evolved over the years from collections of abstract shapes to figures that evoked more concrete associations to an outside observer, such as rocks, birds, and plants, and even, increasingly, people. These appeared in spatial arrangement whereas Cohen did not intend three dimensions. This spatial depth was created through the layers of figures (Nake, 2012).

Harold Cohen explains in his publication of 1982, “HOW TO MAKE A DRAWING.”, the story about AARON, the program as a student under education, that started its study in 1973 at the Stanford University (Cohen, 1982). The development of the ‘machine-based’ student necessitated the fundamental instruction of basic skills acquired by ‘human’ painters. This included teaching the machine how to manipulate a drawing instrument on a paper surface, moving around like a human hand. It was important that AARON had an excellent memory to keep a long list of instructions to

follow. These instructions, in other words the rules of the expert system, were defined sufficiently in detail to allow making decisions continuously based on state changes of the drawing with no additional details to the system. In difference to a human student, basic cognitive skills, even at a primitive level, were lacking by the machine at start. Cohen described them as skills that develop in early childhood and are almost built into the “hardware” of human, such as the ability to recognize the difference between figure and ground, and the difference between closed and open forms. Just as a kid acquiring soft and technical skills in life, AARON as a computer program was expected to acquire those basic skills that were not built in its hardware. This learning process occurred through the executing of instructions with increased complexity over time. A machine that was educated by a set of instructions was limited in developing an authentic voice. The teacher, here Harold Cohen himself, was also a collaborator of the painting activity, for example while manually coloring of the initially generated black and white drawings. Over the years, he recognized that his student, AARON, became capable of generate drawing so much better than Cohen himself. There was a time when AARON’s work, and productions were very much in demand in the art world. However, Cohen was losing his interest in his student due to design limitations of AARON, mostly depending on the expert systems design. AARON was not able to learn from experience, it worked based on complex systems of instructions. It did not have the physical existence required to gain physical skills like a human using its body. Every single action had to be formalized precisely for it to behave. Eventually, AARON became a structure of a set of rules and instructions. Any change on AARON in terms of rules and instructions was forcing change on its structure. Considering the limitations related to its design, AARON was abandoned after so many years due to lack of its adaptability for new purposes, as its creator and instructor Harold Cohen explained. Later, another version of AARON 2 was released pursuing creativity. Rather than storing information about “what to do” based on a set of instructions, the novel AARON was aimed to be designed to have a representation of “how to” knowledge. The capability of self-modification by experience was aspired (Cohen, 1982). Cohen aimed designing a learning system in the path of achieving artistic creativity breaking the limitations of a knowledge-based expert system.

Harold Cohen’s AARON was based on an activity-oriented generative approach, in other words, it was designed to handle a drawing tool’s movement by the machine and

thereby generate visible drawings for the human observer. Frieder Nake worked on an algorithm-oriented approach and developed *Generative Aesthetics I*, little earlier than AARON's development, in 1968-69. Nake's program was aimed generating an image based on the conditions defined in a set of data. The theory of information aesthetics inspired Nake's work. A visual artefact was considered as a *sign* in the information aesthetics and a schema of the signs with their associated relative frequencies was called a *sign schema*. Accordingly, images created using same signs with the same frequencies were belonging to the same class. The theory was built to bring in objective criteria into aesthetics and eliminate the subjective value judgement (Nake, 2012).

In 1966, Nake programmed "walk-through-raster" in "ALGOL60" where the instructions were stored on a punch tape for a *Telefunken TR4* of the Stuttgart University. The output of the program execution was printed by a Zuse Z64 Graphomat eventually. The program simulated a short memory by selecting signs from a set of choices depending on the last choice and a decision procedure by which signs at selected positions were exchanged according to programmed transition probabilities. One of the "six modes" through a field divided in rectangles was entered and the next transition computed. Nake's "walk-through-raster" was coded to execute measurements according to information aesthetics criteria like redundancy and information values. The measurements were coded as a "preselector" of the generated signs in Nake's *Generative Aesthetics I* program with statistic measures for the frequency of colors (Dreher, 2020).

Generative Aesthetics I introduced quantified measures of surprise and conspicuity for each sign used them as constraint to define the interval of feasible values. A maximum and minimum value were also defined, and the problem turned into a non-linear optimization problem with discrete probability distribution solution. The distribution was called "the statistical pre-selector" that represented the set of all images satisfying the constraint. An image was generated next based on the sign schema as a hierarchical color distribution according to the previously determined probabilities. This structure to generate the image was later called a "quadtree" in computer science where the probability of the whole image is distributed into four smaller quadrants by the generative algorithm with the sum of the total remaining the same. The same was repeated for each quadrant where the procedure terminated when a quadrant was

covered by single color the minimum length is reached by size. *Generative Aesthetics I* program worked according to this principle where quantitative criteria were defined for the entire image to satisfy as condition and implemented into discrete probability distribution solution applied iteratively in quadrees of the image with the global condition being always maintained (Nake, 2012).

Generative Aesthetics I had not realized its full potential due to several issues. The experiments were not systematically designed, the results were not analyzed carefully enough, and moreover, other researchers were not sufficiently involved in the process. Nevertheless, aesthetics was generated objectively resulting in an image printed by the automated program. Nake himself defined his efforts as a work of a scientist rather than an artist (Nake, 2012). This statement is reiteration of the convergence of arts and science in the production of computer art.

3.3.3 Digital poetry

“The question of defining digital poetry devolves to the question of poetry itself, of distinguishing what makes a poem a poem and not something else.” as proposed in the foreword of Funkhouser (2007, p. xv). The initial idea of generating poetry with machines relates back to combinatorics. Ramon Lull (1232–1316) is recognized for their contributions to the development of a logical symbolic system applicable across diverse fields of knowledge. The autobiographical poem by Lull, *Cant de Ramon*, was structured in the form of combinatorial poetry. The application of combinatorial principles while generating poetry persisted for centuries, extending into the digital age (Bernhart and Richter, 2021). The art movement *Dadaism* is recognized as a historical model for digital poetry identified by the principles of revolt, disgust, pullback from the absolute and the process of decentralization. Randomizing text through the running of automated computer programs and eventually constructing digital poems, became a logical next step in the *dada poems* (Funkhouser, 2007).

Tristan Tzara’s Dada Manifesto, "How to Write a Dada Poem" introduced a stochastic method of literary production involving the deconstruction of newspaper text and its subsequent aleatory reconfiguration. Dadaist method further challenged traditional authorship by a number of other techniques, including the invention of new words, collage, and the integration of non-semantic phonetics. The iterative alteration and

permutation of linguistic units to change established meaning is a representation of cybernetic Dadaism (Funkhouser, 2007).

Generation of initial poets relied on computer programs to synthesize a database and a series of instructions similar to the functioning of knowledge-based systems. Later by mid-1960s, shaped language and poems appeared on media structured by the emergence of graphical and kinetic components. 1980s opened the path to personal computers and development of hypertext along with that. Meanwhile, other experimental forms of poetry continued to be developed, for example, in the form of audio poetry. Eventually, with the emergence of WWW, poetry gained a new dimension through the integration of multimedia, transcontinental, hyperlinking, all facilitated based on advancements in computing and network technologies (Funkhouser, 2007).

The mathematicians Christopher Strachey in Manchester and Theo Lutz in Stuttgart are acknowledged as two pioneering figures within the realm of computer programmed text generation in the 1950s. They possessed the intention to produce literary or aesthetic outcomes. Strachey and Lutz worked with a sense of form and tradition and applied random methods to the machine to invent novel text based on the existing text. In the 1960s, *Gruppe Oulipo*¹¹ was formed with participants experimenting with formal constraint in generating procedural poetry in France. Initial attempts of digital poetry can be considered in relation to these developments. Computers were no longer seen as machines for arithmetic calculations solely, their use expanded beyond that, such as for experimenting with generating arts (Bernhart and Richter, 2021).

Christopher Strachey (1916-1975) was already researching with computer programming in various creative fields. He developed an algorithm to play “God Save the Queen” by Ferranti Mark I computer in 1951. In a year later, he was working on the optimization of his *Checkers* game program for Mark I, and next, he coded an algorithm to generate short text of love letters. The program was producing letters by randomly selecting words and phrases from a given list; the “Roget's Thesaurus of English Words and Phrases”, 1852, by Peter Mark Roget, according to a defined

¹¹ Acronym for *Ouvroir de littérature potentielle* meaning *Workshop for Potential Literature* in French according to Funkhouser (2007, p.34)

pattern. Two patterns were defined to build up the sentences where the letter terminated with a greeting defined according to a formula following 5 sentences:

Two patterns:

My + [Adjective] + [Noun] + [Adverb] + [Verb] + your + [Adjective] + [Noun]

You are my + [Adjective] + [Noun]

Greeting formula:

Yours + [Adjective] + M.U.C.¹² (Bernhart and Richter: 2021, p.13)

Strachey playfully declared the Manchester University Computer; M.U.C., as the author of the letter letting it sign the text at the end. He maintained his position as the actor of the experiment in the background. Human thinking and emotional expression were explored by his algorithmic poetry (Bernhart and Richter, 2021).

Initial computer poetry was mostly based on permutation of a set of base text or language to transform or reorder them into another text form. Algorithmic poetry procedures can be *permutational*, where words are generated by recombination of existing elements into new, they can be *combinatoric* based on controlled or random combination of a predefined list of words, or further placed into syntactic templates as *grammatical frames* to create sense. Accordingly, a set of instructions to generate new words aligned with certain qualifications, a frame to determine grammatical features and a dictionary of base words is required for creating poems by the machine. A typology for generating digital poems is suggested by Funkhouser (2007), where computational text generation and archetypal digital poetry are fundamentally characterized by permutational operations, wherein a source text is algorithmically reconfigured into another structure. Three procedural methodologies are suggested: permutational works by recombining elements to generate new lexical variations; combinatoric works, which synthesize pre-selected vocabularies through controlled or random combinations; and syntactic templates, which are combinatoric and additionally utilize grammatical frameworks to ensure semantic coherence. Funkhouser (2007) also highlights "Code Poetry" as a manual poetry practice that

¹² Acronoym for *Manchester Universal Computer* (Bernhart and Richter: 2021, p.14)

although emulating the formal aesthetics and syntax of programming languages is not a computational work.

Theo Lutz (1932-2010) is known for his main work “Stochastischen Texte”¹³ of 1959. While he was working on his *graduation thesis*¹⁴ in Electrical Engineering at the Stuttgart Technology University, three mainframe computers; a Z 22 from Zuse KG from Bad Hersfeld, an ER 56 from Standard Elektrik Lorenz (SEL) from Stuttgart and a Pegasus from Ferranti of Manchester, were made available by the Federal program to promote computing technology at German universities (Bernhart, 2022). Lutz familiarized himself with the Z 22 that he used for programming his computer poem. He was experimenting with random combination of subjects and predicates within a fixed syntactic structure. The combination was established using a software random generator that generated pseudo-random numbers (Bernhart and Richter, 2021).

While Lutz programmed his stochastic algorithms with random variation on the Zuse Z22 computer, his computer program worked on a database of sixteen subjects and titles, each from Franz Kafka’s novel “The Castle”. In the execution, subjects and titles were pulled up based on a randomly generated sequence of numbers and then connected by logical constants to build syntax. The English version of the first six lines of the produced poem¹⁵ is provided below.

Not every look is near. No village is late.
A Castle is free and every farmer is distant.
Every stranger is distant. A day is late.
Every house is dark. An eye is deep.
Not every castle is old. Every day is old.
Not every guest is furious. A church is narrow.
No house is open and not every church is quiet.
Not every eye is furious. No look is new. (Freitag)

Figure 3.19 : Digital poetry by Theo Lutz adapted from (Funkhouser: 2007, p. 37).

¹³ In German, translated as Stochastic Texts to English

¹⁴ Diplomarbeit in original language German

¹⁵ Images of the original printout are available at [Url-5](#).

Lutz slightly corrected the stochastic text in the original German version as it came out of the machine; for example, “AE” was edited into “Ä”, “NICHT JEDES HAS IS WÜTEND” was updated to “NICHT JEDER GAST IS WÜTEND”, which means “Not every guest is furious” in German. Eventually, it was necessary for Lutz to manually edit the machine-generated text before publishing this early example of digital poetry. Human-machine interaction was demonstrated not only while programming, but also while deciding on the ultimate text and reforming the output. Lutz’s program was later implemented by PHP in 2005 by the media artist Johannes Auer and made available as a web page (Auer, 2005; Bernhart and Richter, 2021).

Dreher (2020) highlights that Lutz focused on a procedure for obtaining "aesthetic information" by referring to Shannon's model of language reproduction. That was based on frequency statistics of the use of basic elements and their combinations. However, in the production of a text by machine, as observed in Lutz's poems, there may be a contradiction in terms of the "aesthetic" and the "semantic information" in the resulting algorithmic expression. This outcome and the effect is presented to the reader as an experience.

The method that Lutz used in programming the automated poetry consisted of about fifty commands that had the potential of generating more than four million different sentences. The product was a combinatoric poem constructed by the random combinations of a pre-given word list in a controlled fashion. The language was also built on permutations of certain few words that Lutz chose from Kafka’s story. Similar experiments to generate computer-randomized poetry were conducted in the 1960s in various locations of the world. An interdisciplinary approach that considered mathematics, science, and art as areas to collaborate through computerized methods was unfolding (Funkhouser, 2007).

Theo Lutz was a student of Max Bense, one of the creative advocates of the mid-twentieth century concrete poetry international movement. A leader of the group of scientists in the new sciences (programming, computation, linguistics), he is also recognized as the owner of the idea of transferring textual models of *Concrete Poetry* into *Computer Poetry* experimentation. Max Bense published the “Manifesto of Permutational Art” by Abraham Moles, an internationally renowned scientist of the era, in the *Rot* magazine. The use of permutation was proposed to free creativity from the content and meaning related concerns while the interaction between human and

machine was being investigated to overcome the limitations attached to the human spirit. The activities of new sciences further evolved into the group *Stuttgart School* and Lutz became a member. It is reported that, although admitting the connection to the literary movements observed in his work and the use of Kafka's novel in generating his stochastic texts, Lutz did not make any explicit reference to the previous avant-gardes while explaining his methods. He preferred working as a mathematician and a programmer (D'Ambrosio, 2018).

The "chance" operation was replaced by programmatic constraints in the 1960s when the Oulipo group was established in France. Non-computerized procedural poetry and arithmetical writing was improved with an attempt to seeking for possibilities of combining mathematical structures in literary work. A single formula could lead to the construction of an unlimited number of works as a result of the Oulipo process. Restrictive methods were applied varying from the traditional application of metrics and numerical forms of poetry such as in *sonnet* and *haiku*. In this regard, the "n+7" poem is one of the most well-known Oulipian methodology-generated work where a base text is customarily selected by the poet and every noun within the source text is systematically replaced by the seventh noun following it in a designated dictionary. The movement led to irrational text combinations most of the time, however the transformational formulas generated by the Oulipo group, that did not involve a random composition element, built a basis for later text-generating programs. In the end, they are evaluated as an important reference point for the investigation of algorithmic poetry generation (Funkhouser, 2007).

I AM THAT I AM
I THAT AM I AM
I AM I THAT AM
I I AM THAT AM
I THAT I AM AM
I I THAT AM AM
I AM THAT AM I
I THAT AM AM I
I AM AM THAT I
I AM AM THAT I
I THAT AM AM I
I AM THAT AM I
I AM I AM THAT
I I AM AM THAT.

Figure 3.20 : Brion Gysin's poetry experiment adapted from (Funkhouser: 2007, p. 39).

In the United Kingdom, Brion Gysin experimented with a different approach of randomization in his first permutation poem, "I Am That I Am", where his base dictionary consisted only of those three distinct words making up the phrase. The three words would appear in different orders in every permutation where a poem that would be generated using the five-word phrase would be 120 lines long ($5 \times 4 \times 3 \times 2 \times 1$). Ian Somerville programmed Gysin's algorithm in 1960 where lines of computer-generated permutation poems appeared in block formation.

These early examples of poetry indicate the use of simple form of permutation, sometimes even repetition. Nanni Balestrini, utilized a more diverse type of combination using source text from three pre-existing narrative text from different writers while generating his Tape Mark 1 poems of 1961 (Funkhouser, 2007). The Italian concretist poet selected a piece of text from the *Hiroshima Diary* by Michihito Hachiya, *The Mystery of the Elevator* by Paul Goldwin and the *Tao Te Ching* by Lao Tzu, to construct derivative text. The input materials from the three different sources were broken down into simplified units and then recomposed in a previously arranged collage by the help of the program instructions. Max Bense was aware of the Balestrini works with electronic poetry. He criticized their programming techniques because of the limited heuristic capabilities and the lack of their relevance to Shannon's information theory. Bense argued that they had been simply programmed in terms of

1200 orders in connection to combinations of 10 pre-given elements according to syntax-rules. Eventually, both Lutz and Balestrini produced derivative poems based on systematically changing of some existing text from selected input resources. Literary skills were a necessity in determining relevant materials to contribute to the process of algorithmic poem generation and selecting the outcome (D'Ambrosio, 2018).

In the United States, the Time Magazine issue of 25th May 1962 introduced one of the early computerized combinatorics poetries to the public audience. On page 99, in the Books section, under the headline “The Pocketa, Pocketa School” the magazine introduced A.B., the “Auto-Beatnik”, a computer that could create poetry. The corresponding article described two different poems generated by the computer.

BOOKS

The Pocketa, Pocketa School

*Few fingers go like narrow laughs,
An ear won't keep few fishes,
Who is that rose in that blind house?
And all slim, gracious blind planes are
coming,
They cry badly along a rose,
To leap is stuffy, to crawl was tender.*

Faced with this poem, any competent modern critic could easily go to work. He might first allude to its use of alliteration ("few fishes," "few fingers"). Clearly the poem deals with the plight of modern man reaching out for love and innocence but mocked by impending death. Love is the rose stifling in the blind house of modern technology. Note the repeated theme of blindness, and the plane that will bring annihilation to the world. Like the world, human love has no future. And little religious comfort. (The fish was an early symbol of Christian faith, now reduced—hence "few fishes.") Mirth, too, has shrunk to "narrow laughs," though the poet, like Western man himself, fondly recalls the lost gentleness of childhood ("to crawl was tender").

The only way to be sure of the accuracy of such perceptions is to interview the poet. In the case of this one, that would be impossible. For the poem, printed in this month's issue of *Horizon*, is the first tentative work of a sophisticated computing machine.

It works for the Librascope Division of General Precision, Inc., in Glendale, Calif. Fed with a vocabulary of 3,500 words and 128 different patterns of simple-sentence syntax, the computer can turn out hundreds of poems. Because these creations are as intelligible as some beat poems, the computer's engineers call it A.B.² (for Auto-Beatnik).

² Not to be confused with such flesh-and-blood poets as H.D. (Hilda Doolittle); AE (George William Russell); or e.e. (e.e. cummings).



A.B. COMPUTER?
Unfree verse.

TIME, MAY 25, 1962

Of course the machine needs help. The words it picks from have to be kept in separate boxes—all nouns together, all verbs, etc. But by drastically cutting down its choice of words—so that the incidence of a subject word reappearing is greatly increased—engineers can make the machine seem to keep to one topic.

Example:
*All girls sob like slow snails.
Near a couch, that girl won't weep.
Stumble, moon, go, this girl might sail
on the desk.*

This girl is dumb and soft.
With other machines also turning to the muse, there is the chance of a whole new school of poetry growing up. No one can say just what it will be like. But with even an auto-beat computer costing \$500.00 to build, the output will certainly not be free verse.

Götterdämmerung Revisited

THE DECLINE OF THE WEST [414 pp.]
—Oswald Spengler—abridged by Helmut Werner—Knopf (\$6.95).

No gloomier metaphor was ever coined to lend a semblance of shape to man's long struggle through history. Cultures, said Oswald Spengler, are limited biological forms of life—like inchworms, like oak trees, like men. Mysteriously born, they inexorably grow old, decay according to discernible pattern and then die. What is more, Spengler insisted, Western culture has already reached the last stages of its allotted life span.

A trail-eyed German high school teacher, Spengler looked at history not as a linear series of events but as the organic flowering and dying of eight major cultures: ancient Egyptian, ancient Semitic, Peruvian, Chinese, Mexican, Middle Eastern, Greco-Roman and Western. All had flourished for the same amount of time (about 1,200 years). All showed the same development. By comparing the dead to the living, the historian could tick off the inevitable signs of decay and predict how death would come again.

Staked Continents. Writing in a shabby Munich apartment just before and during World War I, Spengler gloomily concluded that history was witnessing the decline of the West. As in the "age of the Caesars," art and music had lost all real creative vitality. Power over the affairs of men had centered in a few enormous cities (megapolises). Soon the masses of people, without hope or sense of form, would turn to a "second religiousness," clinging to blind faiths out of desperate need, while a series of world leaders backed by enormous military power would vie with one another over the destruction of civilization. During the final world rivalry, he wrote, "whole continents will be staked." The great powers "will dispose at their pleasure of smaller states, their territory and . . . their men alike."

Partly because this prophecy bears a shadow-image likeness to today's world, the original, repetitious, two-volume book,



HISTORIAN SPENGLER
Other glooms.

skillfully pared to a highly readable single volume, has just been reissued. Often damned but still cited (the very title can turn a whole evening into disputation), it is still a provocative and often dazzling book.

Dark Prophet. *The Decline of the West* first appeared when the last afterglow of 19th century optimism had guttered out. The exhausted postwar world swallowed Spengler's gloomy brew as a confirming, almost a soothing draught. What matter if the drink were hemlock? At least the worst was known. *The Decline of the West*, despite its Germanic prolixities, sold more than 100,000 copies in the first eight years, mostly in Germany. Spengler was the talk of every campus.

He also became the object of one of the hottest historical assaults ever. The body of serious historians angrily excommunicated him for offenses of pride, ignorance, plagiarism and inaccuracy. The humanists could not forgive him for his constant and unalterable pessimism (death of the West is inevitable) and his firm determinism (a culture cannot change its historical destiny).

Shot Down. As they would later with Arnold Toynbee, whose sweeping theory of flowering civilization resembles Spengler's earlier conception, teams of specialists—anthropologists, economists, art critics as well as historians—fell upon the cosmic thinker. Toynbee is an immeasurably more learned and more scrupulous scholar than Oswald Spengler, and his Christianity helped him to see not only the possibility of self-rejuvenation in a dying civilization but the hope as well of a spiritual development for mankind.

Under attack, Toynbee merely revised some of his broader conclusions. Spengler was all but shot down in flames. The experts demonstrated that he knew almost nothing about Chinese culture, nothing at all about Mexican. His *Time Chart*, marking off the exact number of years

99

Figure 3.21 : The Pocketa, Pocketa School adapted from (Time: 1962, p.99).

The vocabulary selected for A.B. to generate the poems was limited to 3500 words and the syntax was included as part of the 128 sentence patterns. The outcome remained thematic, as a result. Later in the 1960s, *The Computer and the Arts* exhibition at the Institute of Contemporary Art in London became another strong indication that computerized literature became a serious and public practice. The event was curated by Jasia Reichardt in 1968. The 1960s also opened a path to rather graphical representations of digital poems and these became visual and kinetic works based on mutation differentiating from the initial works that were based on permutation. Some of those works were in the form of fixed objects whereas the others were moving (Funkhouser, 2007).

The early examples of digital poetry were influenced by the literal artistic movements of the era they were generated. As concluded in the observations about the origins of computerized text generations by Funkhouser (2007), the early examples of digital poetry starting from late 1950s were generated by a blend of randomness with order using technical art, and eventually changed the way humans interact with language and literature. Max Bense's theoretical work provided a strong basis for computer poetry, yet his student Theo Lutz's experiments with the practical generation of the algorithmic poems were not dependent on the movements of the time, especially those connected to literature. Nevertheless, Dadaist techniques impacted most of the combinatoric and permutational early digital poetry works. Even though aleatoric poems resemble open-form poetry, these digital poems were not generated purely based on chance occurrence, they were usually preconfigured to be randomized and contained certain fixed features such as syntax and other rules defined by the human author. Input text selected by the author remained also important to generate meaningful outcome. The digital technologies of the time were still immature during the central decades of the twentieth century. Early text-generated poems were constructed mainly based on two different approaches. First approach was manipulating a pre-existing text by re-presenting or rearranging the words which was followed in derivative works such as in the experiments of Theo Lutz. The second approach was used more extensively that relied on programming an algorithm to select words from a database of multiple "lists" to construct lines or sentences. In this approach, text in the database could be original texts written by their or other authors or the human interacting with the system could add their texts. Randomization and

permutation in text generation have remained important for digital poetry. Notably, the introduction of computer poems and hence digital poetry occurred several decades earlier to the advent of the WWW. The endeavors of the poets editing in the web environment played an instrumental role in extending digital poets to the present.

3.3.4 Comparative analysis

This section is dedicated to an analysis and synthesis of the previously explained outcomes of study in the selected creative art domains of music composition, visual arts and poetry by the computer.

The interaction of technological developments and art movements gained a renewed dimension with the nascence of computers in the mid-20th century. During this period, algorithm-based creative works emerged.

Computer literature and computer graphics emerged following similar algorithmic principles. The approach implemented by initial computer poets, especially in the works of Christopher Strachey and Theo Lutz was adapted in the 1960s by the pioneers of computer graphics Michael Noll, Georg Nees and Frieder Nake. The common approach used in computer literature started with a selection of input elements to be stored in a database and included a syntax to apply while combining these elements. A random generator was the key component of the computer program to construct the texts with a described determination of frequency to select the elements. The graphics version of this approach used visual elements instead of textual signs. Thereby, information aesthetics guided the artistic creation by defining optimum relation between order and information for the aesthetic achievement. The procedure for the computer graphics substituted words by the visual elements in the starting database. Combination with the help of the random generator varied the position and length of the visual elements in an arrangement of the whole plane. The frequency of selecting the visual elements and the combinatory method was limited and that eventually impacted the overall view and visual effects of the structured plane (Dreher, 2020). According to these definitions, creating art with computers was like rolling dice to randomly activate a few of the many interaction options within a system with defined boundaries, given inputs, and defined interaction rules, and as a result obtaining unpredictable but calculable outputs. Among the first examples of algorithmic art, graphics and text were fundamentally influenced by the concepts of information

aesthetics that was inspired by the developments in cybernetics and information theory. While some of the human practitioners behind these creative works were related to an artistic identity, others were experimental scientists with mathematical background. All of them eventually crossed paths with computers. Their common motivation was to analyze and define the methodical process of human creativity through painting and poetry production, in an effort to transfer the human creative process to the computer algorithm. The artists experimented with the computer as a tool to produce their art and were aided by them in the production of creative work.

Computer music composition used information theory as theoretical foundation and in its early examples, mathematically based methods, stochastic and random algorithms were implemented, as it was in graphics and poetry. Grammar models were adapted in building theoretical framework. Governing rules, based on music theory, were defined and blended in random combinations. The basic elements established in music theory, such as harmony and rhythmic structures, were defined into algorithms to produce novel compositions by the computer. Rule-based knowledge systems and grammar models were subsequently applied during the twentieth century. The computer was used as a laboratory environment to describe the processes of human music composition and experimental studies were carried out.

During the mid-phase of the twentieth century, computer-based painting, poetry, and music production were based on the theoretical foundations of cybernetics and information theory. Researchers in the field utilized mathematical models and statistical data-based calculations as in other algorithmic processes. The large data pools and models based on them, which form the basis of today's artificial intelligence, did not yet exist. The algorithms at the beginning worked with data sources that were not easily scalable, such as expert systems, where limited data was supported with stochastic methods and predictions to generate creative outcomes. Art with computers was produced by controlled randomness, given a set of data input and operational rules as far as the technical possibilities of the period allowed. While dealing with these experiments, scientists and artists were looking for a systematic way to understand how the human creative process works.

It is possible to make inferences based on observations about the pioneering algorithms used in all of the three creative areas subject to this dissertation. Accordingly, rule-based algorithms were commonly used. In computer music composition, rules based

on music theory were defined and blended in random combinations. The basic structures of music theory, such as harmony and rhythmic structures, were defined as algorithms to produce compositions. In computer-aided image production, which started with graphic drawings, the rules and mathematically based techniques that define how the algorithm should act on the space plane were applied, and production was diversified by randomness. In later years, such as in the example of AARON, the rule-based algorithms were still applied on the expert systems structure designed by the program's inventor Harold Cohen. Shapes and forms were all generated by the established rules. The artist had the choice to select parameters to let the program emulate certain artistic style. Initial poems were also produced by using rule-based algorithms. The rules mostly involved spelling and grammar. Combinatorial algorithms were applied on input data usually based on ready-made word lists and grammar rules to generate random texts. The semantic meaning of the outcome text remained often opaque. Although these early algorithms produced results that were limited in creativity and debatable in terms of the artistic merit of their outputs, they were the first milestones and paved the way for the more advanced models that followed in AI.

3.4 State Of The Art: Creative Algorithms

The Ancient Greek referred to both art and craft using the umbrella term "techne" where both concepts were being shaped as part of their daily life as explained in Özselçuk (2023). Art and technique could not be considered separately from each other in the *Ancient Greek*, however, the *Renaissance* and the *Age of Enlightenment* introduced art as a separate process of creation. This division is assumed to be fostered by the emergence of individual areas of expertise and the separation of metaphysics from natural sciences. Milestones and impactful periods in the history such as the invention of the printing press, the Industrial Revolution, and the introduction of photography contributed to the development of the mechanical approach on arts landmarking the modern art period. There has always been a collaboration between art and technique in the history where the artists used available tools at their time when producing works of art. Eventually, digital art was formed as the art of the digitalized world and the production of computer-based objects, not necessarily in the form of physical objects, became possible. Digital art is created using digital media

technologies and the computer in the production process. In the performance of contemporary digital art, the audience is transformed into an interactive participant rather than a spectator of the artwork. Thereby, the audience can better perceive the artwork and witness the artist's production process by being involved to the process through interaction. Digital art designs a fictional universe by making additions to the perceived existing world artificially. The artificial intelligence applications in digital art may simulate an experience for their audience that would be impossible to experience in the real world. The digital art exhibitions, for example of Refik Anadol who introduces himself as a media artist, provide a variety of such digital experiences based on the use of AI algorithms (Özselçuk, 2023).

Artificial intelligence systems emulate human-like behavior, including decision making based on a set of computer codes, technologies, algorithms, and data. In the first quarter of the twenty first century, AI technologies remained limited to certain domain specific tasks which are called *narrow* or *weak AI*. Machines that are anticipated to be capable of emulating full human intelligence, are to be called *general AI*, or *strong AI* according to common definition (Anantrasirichai and Bull, 2021).

AI is considered at the top of the emerging technologies. The producing of current digital art is based on machine learning. Artificial Intelligence's pursuit of creative activities extends to multiple areas of art including music composition, writing novels, screenplays, and poetry in addition to visual arts (Ballı, 2020).

Cambridge Dictionary defines creativity as “the ability to produce original and unusual ideas, or to make something new or imaginative” (Anantrasirichai and Bull: 2021, p. 601). However, AI is known to operate highly on conformity of existing data. Artificial Intelligence’s role is hence accepted as rather supporting or assistive to humans in the creative arts world rather than replacing their creativity. It is nevertheless noted that the first painting created by AI alone was sold for \$432,500 in 2018 (Anantrasirichai and Bull, 2021).

In the essay of “*Can Computers Create Art?*”, with the title relating the audience to Alan Turing’s “*Can Machines Think?*” query, Hertzmann (2018) discusses whether computer programs could be accepted as the author of an artwork and what that would require. It is similarly argued that artistic creation is a social act and hence, people use AI to create the art instead of the computer being the creative owner of the artwork.

Creative applications can be classified by their use of corresponding AI technologies into five groups according to a review conducted for creative industries in 2021 (Anantrasirichai and Bull, 2021). These are content creation, information analysis, content enhancement and postproduction workflows, information extraction and enhancement, and data compression.

The first category, content creation, is at the core of the activities of artists and designers. Text generation, music and image generation are all utilizing machine learning algorithms to recognize patterns and create new content. The second category, information analysis, is needed for AI to process training data to analyze the characteristics, classify content and predict reliable outcomes. Content enhancement and postproduction workflows are the next category of creative applications where they assist AI to improve both quality and management of original content that is not fit for the purpose of the target audience. Images, audio, and text all fit into that category benefit from these intelligent assistance tools to improve content due to for example noise caused during acquisition or degradation over time. Contrast enhancement, colorization and restoration are sample application areas for images. Information extraction and enhancement application category is useful for AI based on deep learning technologies with the help of convolutional layers which can efficiently perform statistical analysis from low to high level through neural networks and thereby abstract meaningful and representative features. The information extracted through a signal usually requires certain level of enhancement or transformation. The review on artificial intelligence in the creative industries investigates applications especially for images and videos under this category. In supporting the creative process, segmentation methods are useful as classification systems to detect or identify objects as well as recognition of images, speech, and music. Object tracking to locate items in consecutive video frames, image fusion to combine multiple images, 3D reconstruction and rendering are tools that employ deep learning techniques. Finally, data compression as the fifth category of creative applications in the review covers deep neural networks for image and video compression that offers greater coding gain than conventional approaches. Generative adversarial networks is widely used in most of the recent creative applications. It is expected that in the near future AI will be most implemented based on Machine learning (hereafter ML) algorithms as a tool or as collaborative assistant in the creative field. Convolutional neural networks

(hereafter CNNs), generative adversarial networks (hereafter GANs), recurrent neural networks (hereafter RNNs) and deep Reinforcement Learning (hereafter DRL) are introduced as part of ML (Anantrasirichai and Bull, 2021).

Machine Learning originate from the neuron-based models proposed in the 1940s (McCulloch and Pitts, 1943). An artificial neuron receives one or multiple independently weighted inputs and adds them by the help of a non-linear activation function which represents the neuron's action potential. The output of the activation function is then transmitted via its axon to other neurons. The multi-layer perceptron (hereafter MLP) is a form of artificial neural network (hereafter ANN) which connects its neural units in a multi-layered architecture. This type of design became popular in the 1980s. The training process in MLP was enhanced by the introduction of backpropagation algorithm in the 1970s which became popular after 1986 when it was demonstrated by the example of several neural networks that backpropagation worked faster than earlier approaches (Rumelhart et al., 1986). The error backpropagation was important enhancement as it helped computing the gradient of a loss function during the training process of the neural network with the loss function producing a real number to represent the cost of an event. The training process aimed eventually minimizing the loss function over the multiple presentations of the input dataset (Anantrasirichai and Bull, 2021).

Machine Learning algorithms are data-driven, they use huge amounts of data to directly learn from without depending on a predetermined model, unlike the mathematically model-driven technologies of the past. Data is important for effective machine learning. In this regard, data augmentation and synthesis techniques are used to expand, adjust, and rebalance samples in training datasets for reliability and to avoid imbalance and bias. Augmentation techniques are useful in increasing the volume and diversity of a training dataset based on existing data. The need for new data is eliminated thereby and minority classes are better represented avoiding overfitting and bias to majority classes. Synthetic data on the other hand is generated, usually by degrading of clean data, and used for applications where real data is hard to collect and where data augmentation would neither help in increasing the variety in the dataset (Anantrasirichai and Bull, 2021).

Deep learning is a type of ML that bases on deep artificial neural networks (hereafter DNNs) where “deep” represents multiple layers of network of neurons. CNNs

emerging in the 1980s are used when data being processed is distributed into multiple dimensions such as in images. CNNs are a class of deep feed forward ANN where training occurs through convolutional layers. CNN is designed to learn by increasing complexity from low-level features through subsequent layers to high-level features that more strongly relate to semantic meaning and a higher-level understanding of the represented data. The basic CNNs are also called encoders where learning happens based on a representation, a compressed version, of a set of data with usually less parameters than the original input. Deconvolutional layers or transposed convolution layers operate as decoder where they can then enlarge the size of the feature map to the original input. The encoder-decoder models are convenient to use in creative applications such as style transfer, image restoration, contrast enhancement, colorization, and super-resolution. There exist also advanced CNNs supporting modified convolution operations for specific applications; for example, residual learning became an important part in contrast enhancement, colorization, object recognition, and denoising. These features made deep learning a powerful choice in pattern identification, analysis of information, and future prediction (Anantrasirichai and Bull, 2021).

GANs were proposed in 2014 and became very popular in many applications including creative processes. They are innovative approach in using two neural networks that compete to each-other to generate new, synthetic data that can pass for real data. The computing networks are called *generative* and *discriminative* where the former is usually a deconvolutional neural network and the latter a CNN. The first module creates a product as the generator and the second module becomes the discriminator examining whether the product is original or was created from the first module. The generative network tries creating outputs that look like real data until that the discriminative network cannot tell whether they are real or synthetic. Eventually, ultimate outcome becomes as similar as possible to real product by eliminating deceptive results. The output created by GAN-based methods are usually limited in terms of size and are in the form of relatively small image squares (Anantrasirichai and Bull, 2021).

Variational Autoencoder (hereafter VAE) is another known deep generative model which is an autoencoder regularizing the encoding distribution to support the generative process. New data is generated by the decoder using this distribution. VAEs

qualify as more stable during the training process in comparison to GANs which are on the other hand better performing in the production of realistic images. Another form of ML is implemented by the RNN that are commonly used to perform sequential recognition. Typical applications of RNNs include speech recognition, handwriting recognition, and music generation where they are also used for image and video processing. Finally, the reinforcement learning (hereafter RL) is a ML algorithm that is trained using a simulation model without the need for a predefined dataset to make a sequence of decisions. ANNs are combined with an RL architecture in DRL where the RL agents learn in a policy-based environment by the help of rewards and punishments to choose best actions and achieve their goals. The application areas of RL in the creative field include storytelling, caption-from-image generation, and gaming (Anantrasirichai and Bull, 2021).

Besides the potentials, there are also challenges foreseen for the creative applications of AI in future as reported in Anantrasirichai and Bull (2021). UNESCO informed that AI will potentially impact culture, education, scientific knowledge, and communication and information-related digital divide issues and moreover the collaboration between intelligent algorithms and human creativity may introduce challenges for the rights of artists in the creative field as cited in Anantrasirichai and Bull (2021, p.635). Issues of piracy and originality may require action. Apart from that, AI learning algorithms being mostly data-driven, distribution and representativeness of training data is vital to cope with bias. Usually, a feedback framework is involved with human interaction in the loop where they check the outputs from AI system to make critical decisions and feedback faulty areas to adjust learning model. Supervised learning by AI relies on data readily exist or is labeled by humans before entering training the model. Creativity usually requires combining ideas from various domains in abstract but coherent way driven by curiosity and experimentation and true creativity does not have pre-defined outcomes. Data labeling for creative type of applications remains a challenge. Increased diversity and context are required for the training of creative AI. It is predicted that the future AI technologies will utilize new computational solutions such as quantum computing or AI may converge with blockchain technologies. Apart from these, later AI techniques do not resemble human mental processes, for example the data driven learning approach with error backpropagation is not detected in human learning. Instead, humans learning is

impacted by genetics, experience and by reinforcement mechanisms of prediction and failure. The next generation of machine learning may utilize reinforcement learning and the transferring of knowledge to other scenarios that were not previously experienced by the individuals. This may add advanced form of generalization and innovation to AI.

Merriam-Webster defines art as “the conscious use of skill and creative imagination especially in the production of aesthetic objects; the works so produced” (as quoted in Mazzone and Elgammal:2019, p.1). Nevertheless, throughout the 20th century, that approach was extended not only to cover “not so aesthetic” objects like in the introduction of conceptual art, but moreover, art did also not necessarily produce physical objects such as in the example of performance arts. Mazzone and Elgammal (2019) further explains that Marcel Duchamp’s practice was groundbreaking and eventually the artist’s intention, institutional display, and audience acceptance all became important to decide whether something can be called “art”. Algorithmic art emerged as a term in the meanwhile to define art that could not be produced without the use of computer programming. One of the most famous examples of algorithmic art was produced by Harold Cohen and his program AARON. Later, the development of machine learning algorithms such as GANs changed the way of algorithms were used for creating artwork. In the past, algorithms had been used to exactly define by certain rules the targeted aesthetics in the output. The modern approach enabled the computer algorithm to generate the outcomes according to the aesthetics understanding that it captured by machine learning techniques. The training was conducted based on a dataset of sample art (for example a collection of images) as input to the ML algorithm. The human artist orchestrated the AI creative art process starting with the selection of input dataset to feed into the generative AI algorithm to imitate them. This was also called *pre-curation*. The human artist could tweak the generative AI model, in other words the algorithm, during the process. Eventually, the artist examined many output images to create the final collection. This process was called *post-curation*. In the end, AI through the generative algorithm, was used as a tool by the artist to create the artwork.

Carnovalini and Rodà (2020) classifies computer based music composition methods into Neural Networks/Deep Learning, Evolutionary/Genetic algorithms, Chaos/Self Similarity and Agents based systems that have been used for creative work more

recently in addition to existing methods of Markov Chains, Formal Grammars and Rule/Constraint based systems. Although the first artificial neural network-based music generation was noted in the late 1980s, the development of deep learning techniques impacted over time music generation like many other application areas. Genetic algorithms employ a combination of solutions to generate new ones based on a random set of initial solutions and work by selecting better fitting answers to evolve into the optimal solution to the original problem. Specification of a problem remains a challenge, however, genetic algorithms have been used in the implementation of music generation systems, with well-known examples dating to the 1990s. It is noted that these methods are used in a hybrid way, for example by using Markov chains in generating initial population, evolving grammar rules or parameters of a Markov chain and incorporating neural networks or human assessments in the fitness function for the genetic algorithm. Self-similar systems, on the other hand, have been used to generate musical material which serve as inspiration to human composers. This is mainly possible due to the nature of music compositions containing certain degree of repeating patterns and variations in the musical structure and spectral density. These systems are based on chaotic and random decision making processes and due to lack of their aesthetic value are less interesting to AI practitioners. Nevertheless, they provide means to explore unconventional melodies. Ultimately, agent based systems provide a modern approach and a meta technique rather than a specific algorithm for music generation. The agents, autonomous software with perception and action abilities, can cooperate and act as part of a multiagent systems. Various autonomous agents in a system generate improvised melodies according to an algorithm while production is being regulated according to a behavior model maintaining a general agreement between the agents.

The emergence of photography in the history is compared to computers making art as a technology use case where the use of a machine in the art-making process initially encountered resistance (Epstein et al., 2023; Mazzone and Elgammal, 2019). The interaction, in other words a feedback loop, between photographers and painters helped photography gaining acceptance in the art world eventually where the technology-driven art incorporated several formal and aesthetic characteristics of painting into their work and painters examined photography and reformed their painting in return. As a result, photography did not replace painting, but liberated its

dependency on realism, opening the door to Impressionism and the Modern Art movement. In analogous to that, generative artificial intelligence is not expected to demise art, but shall offer a new productive environment with its unique opportunities. Mazzone and Elgammal (2019) further explains that like the camera, computer provides replicative process of image production that differentiates from the singularity and original work of art in human painting. Unlike that, computer generated images do not have any direct referent in nature outside their algorithm, whereas photography depends on things outside of the machine and capture things in the natural world as reference. The computer algorithm does not follow the primal pattern of most human art creation that result from inspiration by something observed in the natural world. The lack of referent in the natural world converges AI generated art with the conceptual art where the creative act is in the mind of the artist. Both in conceptual and AI-generated art, the creative process does not necessitate resulting in the form of an object. Physical outcome becomes optional.

Computer algorithms continue transforming the art world. Using computer-based methods provides advantages in the speed and scalability and supports practitioners in experimenting with unfamiliar elements introduced by AI. Furthermore, easy access to tools and methods, and the cost efficiency of their usage make automated art making attractive for the producers. Eventually, the use of AI in the creative industry is impacting production processes and the overall experience of the audience (RaNa, 2025). Apart from that, the introduction of blockchain technology and the concept of Non-Fungible Token (hereafter NFT) reformed the definition of value and possession of the art works. Both the production and the consumption of art continue evolving through digitalization (Günay and Özdemir, 2024).

This chapter concludes by acknowledging the ongoing fast-paced transformation of artificial intelligence technologies within the realm of creative arts, alongside the broad spectrum of domains impacting human-based endeavors. The presented dissertation work draws upon scientific sources current as of the first quarter of the twenty-first century, reflecting the academic landscape of the early 2020s. Periodic updates will be required to integrate future advancements as the field continues to evolve.

4. CONCLUSIONS AND RECOMMENDATIONS

This final chapter outlines the main arguments and research findings of the dissertation. It also provides a summary of the conclusions reached by combining all the information. Subsequently, the verification of the hypotheses proposed in the introduction will be provided. The chapter will end by a discussion of the implications of these outcomes and recommendations for future research.

4.1 Summary Of Key Outcomes

The endeavor to mimic intelligence in inanimate objects can be traced to before the rise of Greek civilization, evidenced with early pictorial representations of automation. From a scientific standpoint, the mechanistic worldview has historically aimed to explain the natural universe, encompassing both physics and biology. This innate urge of humankind to explain the nature from a mechanistic view led to the development of automatons as self-moving devices. Technological artifacts were designed by observing certainty and regularity in nature to explain planetary movements and the behavior of living organism (Price, 1964). Philosophical systems have extensively examined objects engineered to mimic features of living beings, and these significantly impacted cultural themes throughout history (Siciliano and Khatib, 2019).

Hellenistic engineers were among the initial innovators of automation design. Alexander's conquest of Asia in the latter half of the fourth century B.C. led to the formation of a multicultural, creative environment that integrated Greek, Asiatic, and Egyptian scientific and technical expertise (Guarnieri, 2010). During the period called the Golden Age of Islam, which extended from the eighth to the thirteenth centuries, various great philosophers and scholars appeared in history and their works influenced the development of Western philosophy and science. Ismail Al-Jazari, the medieval polymath and engineer is well known with his inventions of complex machines and mechanical devices that predate the first primitive mechanical clocks in Europe by decades, and thereby represent an important contribution to the foundational history of automatons (Guarnieri, 2010; Kaplan, 2023).

In the fifteenth century, automatons became more mechanized, and the first modern measuring machines and mechanical clocks were designed. Humanoid automatons are observed in Leonardo da Vinci's designs (Gök and Gülaçtı, 2024; Guarnieri, 2010). The craft tradition and the printed book of the Scientific Revolution of the sixteenth and seventeenth centuries influenced sophistication of the design of astronomical and biological automatons. The cities of Nuremberg and Augsburg emerged as craft centers of skilled clock and instrument makers (Price, 1964). The "clock" as a metaphor was used in the seventeenth and eighteenth centuries for the mechanistic interpretations of the nature. It served as a paradigmatic illustration, reflecting the machine technologies available at the time (Mul, 1999).

Automatons of the eighteenth century represented a significantly higher degree of mechanical complexity and technical sophistication than samples from preceding and subsequent centuries. Besides, these devices were significant for their role in indicating the approach of the Industrial Revolution (Voskuhl, 2018).

Eighteenth-century automatons were designed in terms of their production material and working principles based on an approach that imitated living beings both in the internal structures of the objects as well as on their visible external surfaces. The idea of imitation gradually became the basis for the thinking system in designing automatons. Baron Wolfgang von Kempelen's Chess Playing (Mechanical) Turk, and the Musician Lady automaton designed by the Swiss clockmaker Jaquet-Droz were among the remarkable inventions of the century (Riskin, 2003). Kempelen's chess-playing Mechanical Turk, despite its deceptive design that concealed a human operator, proved pivotal for subsequent research and discovery. While earlier automatons primarily focused on mechanically imitating bodily movements, the Mechanical Turk additionally simulated human-attributed intelligence (Fron and Korn, 2019).

The nineteenth century witnessed a transition in technological focus, with the rise of the Industrial Revolution diverting attention from automatons towards groundbreaking technologies such as steam engines. Consequently, while still considered magnificent and impressive inventions, automatons primarily served as objects of public admiration and entertainment. The inherent connection between automatons and large-scale industrial machinery is nevertheless undeniable. Charles Babbage's motivation

for pursuing machine intelligence was reportedly triggered by an early fascination with automatons (Coll, 2014).

Babbage was a mathematician and an inventor who worked on building machines capable of performing complex mathematical calculations. He designed the Difference Engines and the Analytical Engine. While these machines were mechanical, they served as pioneering antecedents to modern computer calculations which emerged a century later based on logical design and architecture (Bromley, 1987). Babbage's machines represented an innovation over preceding automatons because the design focused on imitating the human mind rather than the physical body (Coll, 2014).

The first half of the twentieth century witnessed the introduction of the term "robot" through Karel Capek's 1920 play, "Rossum's Universal Robots (R.U.R)". The term derives from the Slavic word "robota", meaning "serving". In the 1940s, the renowned science fiction writer Isaac Asimov articulated his Three Laws of Robotics in "Runaround" to establish principles for human-robot interactions (Sharkey and Sharkey, 2006). With the initial developments in cybernetics, computer science, and artificial intelligence in the mid-twentieth century, a new era was loading in the common adventure of machines and humans.

Artificial intelligence was formally established as a scientific discipline through the interdisciplinary contributions of both social and natural sciences, with these fields mutually influencing each other's development as areas of research. Rene Descartes suggested a direct relationship between language and thought. Within the framework of Cartesian philosophy, Descartes considered the ability to use speech and symbols to exchange thoughts with others as a distinguishable characteristic of humans separating them from the machines (Özcan, 2022). Gottfried Wilhelm Leibniz, who possesses a strong place in the history of symbolic logic, was influenced by Descartes' philosophy, the mathematical mechanism, and the paradigm shifts of the modern age (Hazar, 2022). The mind-machine metaphor began to flourish in the behaviorist school of psychology during the first half of the twentieth century (Penn, 2020). The analogy between machines and the human brain became a dedicated area of scientific research (Hiser and Francis, 2000).

Mathematics and physics were foundational in the establishment of Artificial Intelligence's theoretical framework. Development of formal systems, probability

theory, concept of randomness, and arguments and proofs leading to the incompleteness of mathematics influenced the emergence of artificial intelligence concepts. The progress in physics contributed to related fundamental theories and together with the advances in engineering they enabled Artificial Intelligence's realization.

During the beginning of the twentieth century, mathematicians were seeking to formalize the criteria for validating a proof, leading them to investigate mathematical foundations. In 1920s, David Hilbert worked on establishing a formal mathematical language by the introduction of the "Proof Theory". This language was expected to become a formal system based on an alphabet with a well-defined grammar, a finite number of axioms and rules. Mathematics as a formal system should be consistent, complete, and decidable. Hilbert was looking for a mechanical method, an algorithm, to test the validity of proofs independently of human intuition and intelligence (Karaçay, 2006; Kayaönü, 2000). Hilbert's vision of mathematics as a complete formal system was critically challenged by Kurt Gödel's incompleteness theorems. Gödel demonstrated that there exist questions within formal mathematical systems that are undecidable; that is, the validity of certain propositions within mathematics cannot be formally proven within the system itself (Gödel, 1931).

David Hilbert's decision problem (Entscheidungsproblem) was a central concern for mathematicians in the early twentieth century. Alan Turing also investigated the decision problem, extending its scope further while working on to prove that it did not have solution. He introduced the idea of inventing a single machine, the universal computing machine, to compute any computable sequence (Hazar, 2022). Turing demonstrated through the conceptual universal machine that no general method existed to determine the provability of a given formula within the realm of functional calculus. As a result, it was proven that mathematics, within its formal systems, was undecidable (Turing, 1936).

Progress in physics during the first half of the twentieth century influenced the development of AI through the introduction of foundational texts and theories, furthermore impacted realization, and deployment, shaped by the technological limitations and advancements in hardware prevalent at the time. Among these crucial developments, the theories of thermodynamics were particularly significant, as they contributed to the theoretical groundwork of intelligent machines (Li, 2023). The

concept of entropy as it was understood in statistical mechanics served as a foundational element for the Information Theory proposed by Claude Shannon with the goal of defining a general framework for communication. His work influenced theories of information, ultimately data and the artificial intelligence paradigms founded upon them (Shannon, 1948).

The concept of uncertainty, as established in physics, notably in quantum mechanics, anticipated a paradigm shift in artificial intelligence, moving from deterministic to probabilistic approaches. Not only the objective world, but its mapping within the human mind as a subjective world, thereby referring to the human cognitive process, contained uncertainty. Abstraction, imagination, and randomness were the key features of human thinking relating to intuition, association, analogy, and creation capable of generating an indefinite number of patterns (Li and Du, 2017).

The brain modeling theory that emerged in the early twentieth century proposed the vision that neural networks were heterogeneous systems of neurons. The concept relating to the electrical firing of neurons and the "synapse" was introduced. The scientist Warren McCulloch and Walter Pitts formulated a mathematical theory during the 1940s to model neuronal behavior as Boolean units, using a logical element that toggles "on" or "off" in response to afferent spike excitation. The theory postulated that information was transmitted through the action potentials between the neurons, and only a firing neuron could communicate with other nerve cells (Buhmann et al., 1986).

During the mid-20th century, the concept of the intelligent machine gained prominence. The advent of the computer provided the essential platform for realizing the aspiration of implementing humanoid intelligence (McCorduck et al., 1977).

The story of artificial intelligence from the middle towards the second half of the century can be considered as an accumulation and assimilation of progressing events rather than a set of abrupt shift and sudden discontinuity over time (Newell, 1983). Nevertheless, the conceptualization of AI as a separate discipline is commonly related to the conference event where the term "artificial intelligence" was officially used for the first time. John McCarthy, a young assistant professor of mathematics at Dartmouth College was inspired by the interdisciplinary convergence on the research conducted on intelligent machines and suggested that scientists working on these issues

should spent the summer together in a conference to contribute on the overall progress. A proposal was submitted for a two-month study event at the Dartmouth College in Hanover, New Hampshire, during the summer of 1956 (McCarthy et al., 1955; McCorduck et al., 1977).

The objective of the conference was to address some of the artificial intelligence problems, as it was outlined in the event proposal. The researchers were seeking for theories, abstraction, and formalization in the emerging field of AI. The problem domains designated for study were organized under seven foundational pillars, encompassing the programming of automatic computers, formulation of use of a language by computer, advancing the theoretical work on neuron nets, developing a theory of the size and efficiency of computer calculation, studying the self improvement of machines, formulation of machine abstractions of sensory and other data, and the computational randomness in relation to creativity (McCarthy et al., 1955).

Artificial intelligence research and implementation technologies went through several phases since their emergence. Symbol-based, connectionist, genetic, and stochastic problem-solving approaches appeared, with some remaining viable and others proving ineffective over time (Luger, 2021). AI from the mid-twentieth century was implemented based on symbolic manipulation, expert-systems databases, and data-driven machine learning approaches. The symbolic approach introduced a heuristic symbolic information processor modeling of the human reasoning while the expert systems was an attempt to formalize human knowledge as databases of "if-then" rules (Ali et al., 2023). In the early years of AI, from the mid-1950s to the 1980s, the symbolic AI approach was prevalent, hypothesizing that human thought was using symbols in representing objects and problems (Anantrasirichai and Bull, 2021). The neural network approaches that stem from the 1940s are implemented more recently based on extensive databases to extract patterns and correlations from data, enabling the generation of predictive forecasts (Ali et al., 2023).

The ability to process and utilize aesthetic elements differentiates human cognition from machine intelligence (Arf, 1959). Creativity is considered as a foundational feature of human intelligence (Boden, 1998) and can be related to the aspects of chance, chaos, randomness, and unpredictability. Machine creativities are mainly

manifested through generative systems and heuristic computational models (Boden, 1998; Boden, 2004).

The nascence of computer-generated arts coincides with the emergence of mainframe computers in the 1950s. Cybernetics and information aesthetics concepts influenced early art production experiments by the computer during 1960-70s (Dreher, 2020).

The interaction of artistic creative endeavors with technology gained a renewed dimension with the emergence of computers in the mid-twentieth century. During this period, algorithmic creative work experiments with the computer were initiated. Researchers who were experimenting with the formal definition of the artistic work process used the computer as a laboratory environment to define, run and refine their algorithms. Common objective of the practitioners was to understand the methodical process. The production of creative work with artistic value was not central to the initial experiments with the computational tools. This approach evolved over time and the artist utilized computer as a collaborative partner in supporting and enhancing the human creative process. In the recent studies, human-AI co-creation is emphasized as a dynamic, iterative partnership diverging from the simple automation and delegation of tasks. AI, accordingly, does not replace human creativity but transforms it by adding a strong collaborator. It introduces new questions, forcing new perspectives on the existing structures and experiences. Ultimately, for example in music, the evolution of novel composition is driven by the dynamic interplay between human interpretive adaptability and computational variance (Wang, 2025). In this context, higher acceptance of AI technology correlates to higher levels of creative productivity (Ma, 2025).

This study explored algorithmic approaches applied in music composition, digital visual arts and poetry generated by the computer during the early years of AI. Initial computer poetry, digital visual arts and compute-based music were implemented following similar algorithmic principles. A random generator was used in all fields to activate a few of the many interaction options within a system with defined boundaries, given inputs, and defined interaction rules, and as a result obtaining unpredictable but calculable outputs. The concepts of information aesthetics, inspired by cybernetics and information theory, were applied. Experiments by computer were influenced by information theory, and mathematical methods of stochastic and random algorithmic implementations. The computer was used as a laboratory environment to experiment

with the formalized processes of human creativity. Researchers in all the three creative domains were working on formulizing the process of human creativity and applying that to the computer through the algorithm. In the early experiments, rule-based algorithms were widely used. Creativity was limited and the artistic merit of the produced work was debatable. However, these endeavors contributed to the foundation of subsequent creative artificial intelligence models and an analysis of the process of creativity.

4.2 Verification Of The Hypotheses

This concluding chapter aims to present evidence supporting the validation or rejection of the hypotheses proposed in the dissertation's introductory chapter.

- i. *The trajectory of artificial intelligence represents an ongoing narrative rather than an interrupted historical account.*

The hypothesis is supported by the historical narratives of AI examined throughout Chapter 2. . Moreover, in Chapter 3.1, it is explicitly stated with reference to Newell (1982), that the story of AI can be considered as an accumulation and assimilation of progressing events rather than a set of abrupt shift and sudden discontinuity over time.

- ii. *AI originates from humanity's ancient effort to simulate intelligence on inanimate objects and the mechanistic world view.*

The hypothesis is supported according to the narrative about the pre-history of artificial intelligence documented throughout Chapter 2.2.

- iii. *AI as a field has been shaped by the mutual influence of diverse social and natural science disciplines and conceptually formalized as a field in the middle of the twentieth century.*

The hypothesis is supported by the interdisciplinary foundations presented in Chapter 2.2.2 and the narrative about the emergence of AI as a separate discipline as narrated in Chapter .

- iv. *AI was propelled by strategic research and development during the Second World War.*

This hypothesis is validated by the historical progress that was coinciding with the Second World War and corresponding strategic efforts which contributed to the development of computers and the early AI research as documented throughout Chapters 2.2.2 and 2.2.3

- v. *Creativity as an indication of human intelligence was central during the emergence of AI to the debate on whether machines can think.*

Chapter 3.2 examines this hypothesis by exploring the concepts of creativity as attributed to human intelligence and manifested and applied within the realm of artificial intelligence.

- vi. *The question of whether AI can demonstrate creativity has inspired the field of arts and scientific experiments. An analysis tracing the historical evolution of AI implementation approaches in music composition, painting, and poetry can illuminate the trajectory of computational creativity.*

- a. *Analysis will demonstrate whether common understanding of creativity existed while formalizing for computer implementation.*
- b. *It will present the motivations behind the early experiments in computer creativity.*
- c. *The interaction of technological developments and art movements will be demonstrated by the analysis.*

The entire Chapter 3.3 is dedicated to exploring this hypothesis by examining indications about the existence of a common understanding of creativity, the primary motivations for corresponding experiments and mutual influences between technology and art within the context of early AI implementations of music composition, painting, and poetry. Chapter 3.3.4 provides a comprehensive documentation of the outcomes.

4.3 Implications And Recommendations For Future Research

Artificial intelligence systems emulate human-like behavior, performing decisions through the implementation of computer codes and algorithms, driven by technologies and datasets. In the first quarter of the twenty first century, AI technologies remained restricted to domain-specific applications, a category often referred to as "narrow" or

”weak AI”. Machines expected to emulate full human intelligence in the future are termed ”general AI”, or ”strong AI” (Anantrasirichai and Bull, 2021).

Artificial intelligence, being considered among the emerging technologies, leverages variations of machine learning methodologies to produce digital art. The pursuit of creativity by artificial intelligence extends to a range of artistic disciplines, encompassing music composition, narrative forms (novels, screenplays), poetry, and visual arts (Balli, 2020).

Machine Learning concepts originated in the neuron-based models proposed in the 1940s (McCulloch and Pitts, 1943). Approaches developed over time have evolved into data-driven systems, meaning now algorithms leverage extensive datasets for direct learning rather than depending on predetermined models unlike the earlier mathematically model-driven implementations of AI. Accordingly, data became critical for effective machine learning applications with the growing need for data augmentation and synthesis techniques. These are employed to expand, adjust, and rebalance samples in training datasets to ensure reliability, and mitigate imbalance and bias. Deep Learning is a type of ML which bases on deep artificial neural networks. Deep Learning algorithms are implemented as a powerful choice in applications of pattern identification, information analysis, and making future predictions based on data (Anantrasirichai and Bull, 2021).

The investigation of the historical trajectory of machine creativity highlights a transition from early inquiries preoccupied with the originating subject of the creative act towards the systemic imitation of the creative process itself. Lovelace was challenging the unpredictability of computational creativity dependent on the human origin. Turing, on the other hand, advocated for a method for evaluating machine intelligence based on the observable outcome. The assumption that creativity must remain inherently subjective was diminishing. Modern perspectives treat creativity as a process-oriented phenomenon that can be implemented by a computer with visible end products in terms of ideas or artefacts rather than a hidden, individualistic attribute.

Drawing upon a synthesis of existing literature, Carnovalini and Rodà (2020) suggest that music allows mapping to precise mathematical and computational models in a more streamlined way than other artistic media like poetry or figurative painting eliminating complexities of semantic interpretation from the creative equation, thereby

constituting a fruitful field for computational creativity studies. While this finding due to the inherent structure of music is remarkable, it is important to also note that computational creativity in music is nourished from the advancements in the other fields of creative art. A recent study by Chen et al. (2024) illustrates this by the implementation of a single computational framework that simultaneously generates images and composes corresponding music. This is enabled by spectrograms as visual representation of sound and the application of sophisticated machine learning algorithms such as GANs that originated in the applications of computer based visual art studies rather than music composition work (Anantrasirichai and Bull, 2021). Carnovalini and Rodà (2020) also suggest that existing reviews in the computational music generation systems widely focused on technical methodologies over theories evaluating machine and human creative processes. The understanding of the nature of creativity itself by the study of computational creativity remains an open field to further research.

Existing literature review indicated that social scientists in the computational creativity field tend to examine the creative process itself whereas artists are looking for a way to collaborate with AI to amplify their own creativity. While this provides valuable insight, it is essential to acknowledge that the boundaries between disciplines within computational creativity are not sharply defined. Practitioners frequently operate across multiple domains rather than working in silos; for instance, a composer may also possess mathematical expertise or engage in close collaboration with computer scientists. This pattern has remained valid since the early examples, as observed by the pioneering collaborative work of Hiller and Isaacson. Consequently, research in this field is characterized by an inherent interdisciplinarity that resists rigid categorization. Moreover, historical records of twentieth century, explicitly in the example of Hiller and Padberg, showed that in the early efforts of music composition, the artists were more concerned with an improved understanding of the music composition process rather than the artistic value of the resulting work by the computer. These early endeavors remain significant, as they provided foundational insights into the creative process through the specific lens of musical composition. It is plausible to attribute these outcomes to the nascent state of algorithmic capabilities at the time, which was characterized by relatively modest artistic objectives with the help of technology. As technological capabilities and practical applications have matured, there has been a

corresponding shift in the underlying motivations of researchers within the field. An example of this changing perspective is captured in a statement by David Cope where he described the motivation for developing his EMI project as a direct response to a personal creative crisis. Subsequently, he was looking for a computational “composing partner”, also reflecting an early indication of that computer was becoming a collaborative partner for the artist, rather than being used merely as a tool (Pearce et. al., 2002).

Beyond its potentials, artificial intelligence, and its applications in the creative field in future anticipates challenges. AI will potentially continue to impact culture, education, scientific knowledge, and communication and information-related digital divide issues for future. In the creative field, the interaction of human artists with the intelligent machine algorithms may intensify ongoing debates about the intellectual rights. Issues of piracy and originality will call for improvement actions in the field including effective regulations. Given that AI learning algorithms are mostly data-driven, the elimination of bias in the distribution and representativeness of training data remains a vital issue (Anantrasirichai and Bull, 2021). In the field of music, for example, the cultural bias introduced by training AI mostly on Western-based music forms are problematic topics in the field (RaNa, 2025). Creativity typically requires combining abstract yet coherent ideas from various domains driven by curiosity and experimentation, and true creativity rarely yields to pre-defined outcomes. Data labeling for creative type of applications remains a significant challenge. Increased diversity and context are essential for the effective training of creative AI. Future AI technologies are anticipated to utilize novel computational solutions (Anantrasirichai and Bull, 2021).

Due to the black box nature of systems working based on machine learning, it is hard to evaluate the underlying functioning of the generation process and the usage of dataset and ultimately to control the creative work produced by the system. Apart from the controlling of the generated output of the systems, further challenges involve adding the sense of emotions to the produced outcome by the automated system, and the complexities in utilizing hybrid approaches. As an example, in the field of music generation, obtaining quality of the audio in the outcome, the generation of longer pieces of music by structuring, choosing appropriate representations for the musical

content, and adapting the difficulty of the output to be played by a human are raised as field specific challenges (Carnovalini and Rodà, 2020).

Neural networks remain the most widely utilized approach in the current applications, while state-of-the-art solutions derived from other fields are adapted. The study domain including music composition contains human-centric problems like the objective evaluation and assessment of expressive quality of AI produced artwork. The potential of artificial intelligence to surpass human intuitive capacities and achieve autonomous artistic agency remains an unrealized goal in contemporary computational creativity, marking a significant challenge for the future research (Mycka and Mańdziuk, 2025)

The aforementioned future challenges could be addressed as part of a separate academic research. In addition to these, the topics of artificial intelligence and ethics, alongside their socio-cultural impacts, can be studied from a historical and future-oriented perspective.

From a more localized perspective, developments following Prof. Dr. Cahit Arf's mid-twentieth-century lectures on machine intelligence, in particular, how they influenced subsequent academic schools and institutional frameworks, could be investigated.

For additional future research, the core motivations underpinning contemporary artificial intelligence studies can be fully examined from a historical perspective which initially were driven by the desire to comprehend the cycles of the universe and living mechanisms and fueled by curiosity. In concluding, further in depth analysis of contemporary AI studies in connection to the particular social and scientific disciplines discussed in this dissertation is recommended, investigating the underpinning motivations and the mutual transformative effects of the outcomes, and synthesizing the outcomes by tracing to the historical roots.

This study examined the contributions of computer-based art production work to the overall understanding of human creativity process through a historical review. The result of the research showed increased potential and interest in enhancing individual creativity with the integration of AI as a collaborator, thereby implying renewed definitions of creativity for future.



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CURRICULUM VITAE

Name Surname : İlkem Ahu Şahin

EDUCATION :

- **B.Sc.** : 2002, Boğaziçi University, Faculty of Engineering, Computer Engineering
- **M.Sc.** : 2005, Technical University of Berlin, Faculty of Electrical Engineering and Computer Science, Computer Science (Diplom-Informatik)

PROFESSIONAL EXPERIENCE AND REWARDS:

- 2026 Completed Doctorate at Istanbul Technical University
- 2024- present Working as Program Manager at Harrington HPC Microsystems in Türkiye
- 2015-2024 Worked as Project and Program Manager at Dell Technologies in Türkiye
- 2013-2015 Worked as Senior Consultant at Orga Systems in Türkiye
- 2009-2013 Worked as Program Manager at TÜBİSAD in Türkiye
- 2007-2009 Worked as Internal Auditor and Audit Manager at Vodafone in Türkiye
- 2004-2007 Worked as a graduate student candidate and later as professional Integration Analyst at Motorola in Germany
- 2002-2004 Worked as a graduate student candidate at DAI Labor in Germany

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