Faculty of Architecture, CTU in Prague, Department of Design Modelling

Dissertation

Sound Shape Space

Architectural Representation of Soundscapes with the use of Artificial Neural Networks

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Karolína Kotnour confirms that the thesis was developed on her own.

Karolína Kotnour potvrzuje, že práci vypracovala samostatně.

Prague, 15.9. 2022

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i. Abstract

This doctoral thesis proposes a new strategy for evolving architectural structures based on the idea of adaptation to a dynamically changing environment, with the use of advanced machine learning and AI methods. The evolving architecture uses physical and cognitive processes that are transformed and assembled into structures based on environmental properties and capabilities. The project investigates a living dynamic system as a complex set of natural and cultural sub-processes in which each of the interacting entities and systems creates complex aggregates. It deals with natural processes, communication flows, information networks, resource distribution, dense noise masses, a large group of agents and their spatial interactions in the environment. By significantly expanding existing research, the project creates a meta-learning model useful for testing various aspects of adaptation to a complex dynamic environment. This refers to the difficulty of designing artificial agents that can intelligently respond to evolving complex processes.

This multidisciplinary project transfer knowledge into the field of architectural creation, from cognitive neuroscience and human-computer interaction approaching digital modelling through machine learning algorithms. The theoretical part of the thesis outline novel approaches to grasp space, material and architecture in a models of waves and particles. It contains a study of digital sound-spatial structures - soundscapes. The project is a case study of the implementation of new approaches in architecture that are a cutting edge of the contemporary computing technologies. It investigate applicability of machine learning algorithms in the context of spatial dynamic forces, as a tool for architectural representation of sound and dynamic spatial structures. The second part of the thesis deals with the application of more complex machine learning models for Architectural Intelligence.

The experimental part focuses on the concept of a dynamic environment. Then the concept of evolutionary architecture and Architectural Intelligence is introduced based on the ideas of adaptation to environmental changes. The common machine learning algorithms and neural networks have a limited range as they deal with individual tasks and are not sufficient for modelling complex adaptation processes. Therefore, the thesis propose an approach based on advanced methods such as meta-learning, in which the knowledge gained to solve one task can *be generalized and applied to many other tasks. It presents the applications of meta-learning to analyse and design architecture and tests the proposed theoretical framework of Meta-Evolver in the form of an immersive digital environment.*

ii. Key Words

adaptation algorithms architecture architectural intelligence artificial intelligence brain cognitive complex systems data digital design dynamic environment evolving forms general human computer interaction information processing machine learning methods music neural networks patterns representation sound space spatial structures systems technology virtual

iii. Abstrakt (česky)

Tato disertační práce navrhuje novou strategii evolučních architektonických struktur založenou na myšlence adaptace na dynamicky se měnící prostředí s využitím pokročilých metod strojového učení a AI. Evoluční architektura využívá fyzické a kognitivní procesy, které jsou transformovány a sestavovány do struktur na základě vlastností a schopností prostředí. Projekt zkoumá živý dynamický systém jako komplexní soubor přírodních a kulturních dílčích procesů, ve kterých každá z interagujících entit a systémů vytváří komplexní agregáty. Zabývá se přírodními procesy, komunikačními toky, informačními sítěmi, distribucí zdrojů, hustými šumovými masami, velkou skupinou činitelů a jejich prostorovými interakcemi v prostředí. Významným rozšířením stávajícího výzkumu projekt vytváří meta-learning model vhodný pro testování různých aspektů adaptace na komplexní dynamické prostředí. To se týká obtížnosti navrhování umělých agentů, kteří mohou inteligentně reagovat na vyvíjející se složité procesy.

Tento multidisciplinární projekt přenáší znalosti do oblasti architektonické tvorby, od kognitivní neurovědy a interakce člověk-počítač až po digitální modelování pomocí algoritmů strojového učení. Teoretická část práce nastiňuje nové přístupy k uchopení prostoru, materiálu a architektury v modelech vln a částic. Obsahuje studii digitálních zvukově-prostorových struktur - zvukových ploch. Projekt je případovou studií zavádění nových přístupů v architektuře, které jsou špičkou současných výpočetních technologií. Zkoumá použitelnost algoritmů strojového učení v kontextu prostorových dynamických sil jako nástroje pro architektonickou reprezentaci zvukových a dynamických prostorových struktur. Druhá část práce se zabývá aplikací složitějších modelů strojového učení pro architektonickou inteligenci.

Experimentální část je zaměřena na koncept dynamického prostředí. Poté je představen koncept evoluční architektury a architektonické inteligence založený na myšlenkách adaptace na změny prostředí. Běžné algoritmy strojového učení a neuronové sítě mají omezený rozsah, protože se zabývají jednotlivými úkoly a nejsou dostatečné pro modelování složitých adaptačních procesů. Proto práce navrhuje přístup založený na pokročilých metodách jako je meta-learning, ve kterém lze poznatky získané řešením jednoho úkolu zobecnit a aplikovat na mnoho dalších úkolů. Představuje aplikace meta-learningu pro analýzu a návrh architektury a testuje navrhovaný teoretický rámec Meta-Evolver ve formě imerzivního digitálního prostředí.

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iv. Klíčová slova

adaptace algoritmy architektura architektonická inteligence umělá inteligence mozek kognitivní komplexní systémy data digitální design dynamické prostředí vyvíjející se formy interakce člověka a počítače zpracování informací metody strojového učení hudba neuronové sítě vzory reprezentace zvuk prostor prostorové struktury systémy technologie virtualita

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"For beauty is nothing but the beginning of terror which we are barely able to endure, and it amazes us so, because it serenely disdains to destroy us.

Every angel is terrible."

Reiner Maria Rilke, Duino Elegies, 1923

1. Introduction

The answer is technology, but what was the question? asked architect Cedric Price at a lecture of the same name in 1979 - a question that determines the main goal of this work and the basic questions for advanced architectural strategies. With computational thinking, we enter the whole field of novel approaches to an architectural creation and they allow us to define architecture as computational models written in code of successful architectural strategies - **Architectural Intelligence**.

Due to the main aspect of technologies that penetrate not only into our daily lives, much of data science and data analysis come from many different scientific disciplines. This aspect brings the opportunity to work with data across many disciplines and aspects of human activity and transfer knowledge from biopsychology, human behaviour and perception of space to the architectural design. There is an attractive potential for creating creative tools for processing dynamic forces and data fields. This data is treated as material that is transformed into an informed shared space and living responsive environments. The proposed architectural approach represents data, digital information in the entity that embody some form of *Architectural Intelligence*. By observing what defines and influences people's behaviour, perception, and sensory processing, we uncover the basic behavioural configurations that can be found in patterns of communication or information transmission. The human senses process vast clusters of information that reaches them from the outside world as close distant spaces that they represent. These perceptual mechanisms create a large number of layers of reality, and by decoding and exchanging them, we have enclosed them in shared reality.

Therefore the model of interlocking forms is proposed, and embraced in the place where space ceased to exist, and only the mutable matter emerge. “The creative power of reality lies between three basic areas, and these are vibration, form and movement. The combination of these three areas is a physical world, and in a simplified way what appears to be a solid form is in fact a wave formed by quantum particles in constant motion.”[1] The following text expands on and provides a deeper insight into this arguments. Other aspects and arguments of this work, such as the relationship between number, space and time, are examined and described in the following chapters.

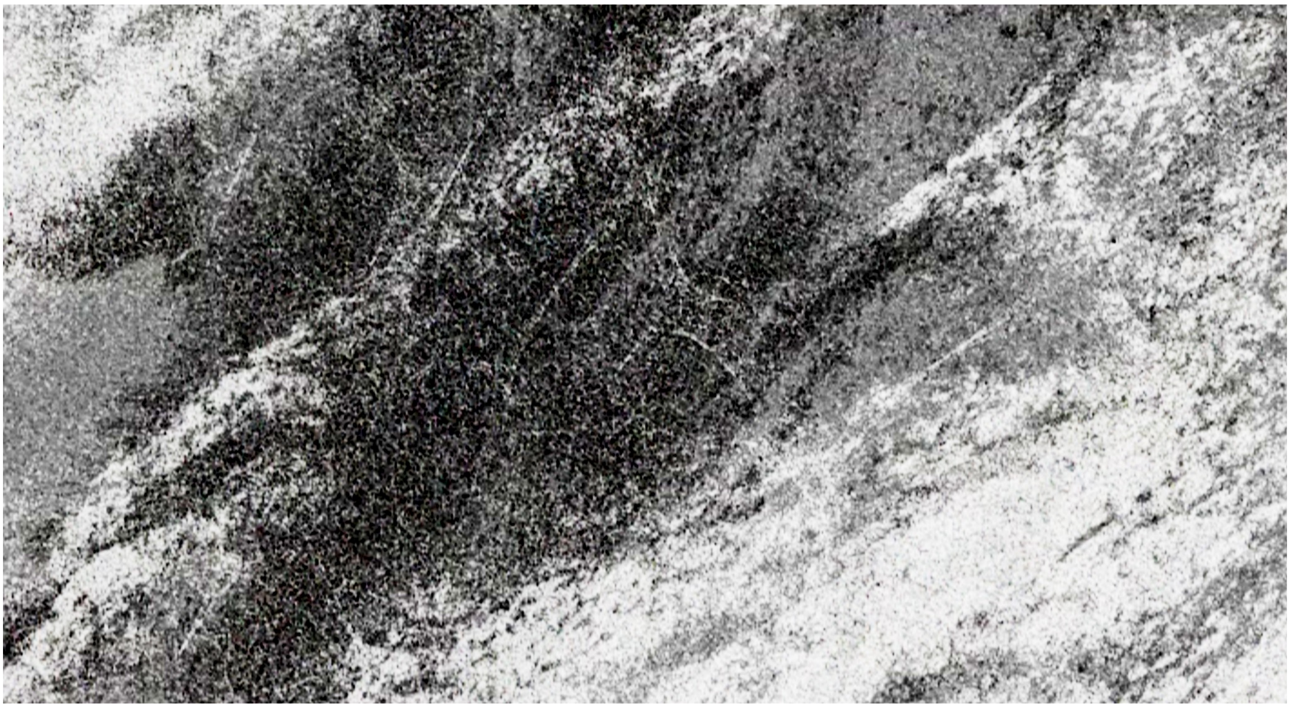

Figure: Karolína Kotnour, Seeing by Learning - Inhabited Soundscapes, 2015

The analytical part of the architectural design requires the processing of a large amount of input data. In the experimental part of this work, the noise field, and brain activity are represented by qubit a quantum bit, particles, waves, and dimensions of compositional models in a virtual *controlled environment*. Virtual composition models provide a platform for testing and assessing the response of emerging environments and situations with respect to the *design theory* and *research hypotheses*. Individual models and prototypes of architectural code, principles and instructions for interaction with the controlled environment, will allow

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[1] Hans Jenny. Cynematics: The structure and dynamics of waves and vibrations. Volume 1. Basel: Basilius, 1967, pp. 13.

detailed observation and evaluation of all data and take them into account in the entire process of design and learning of *Architectural Intelligence*.

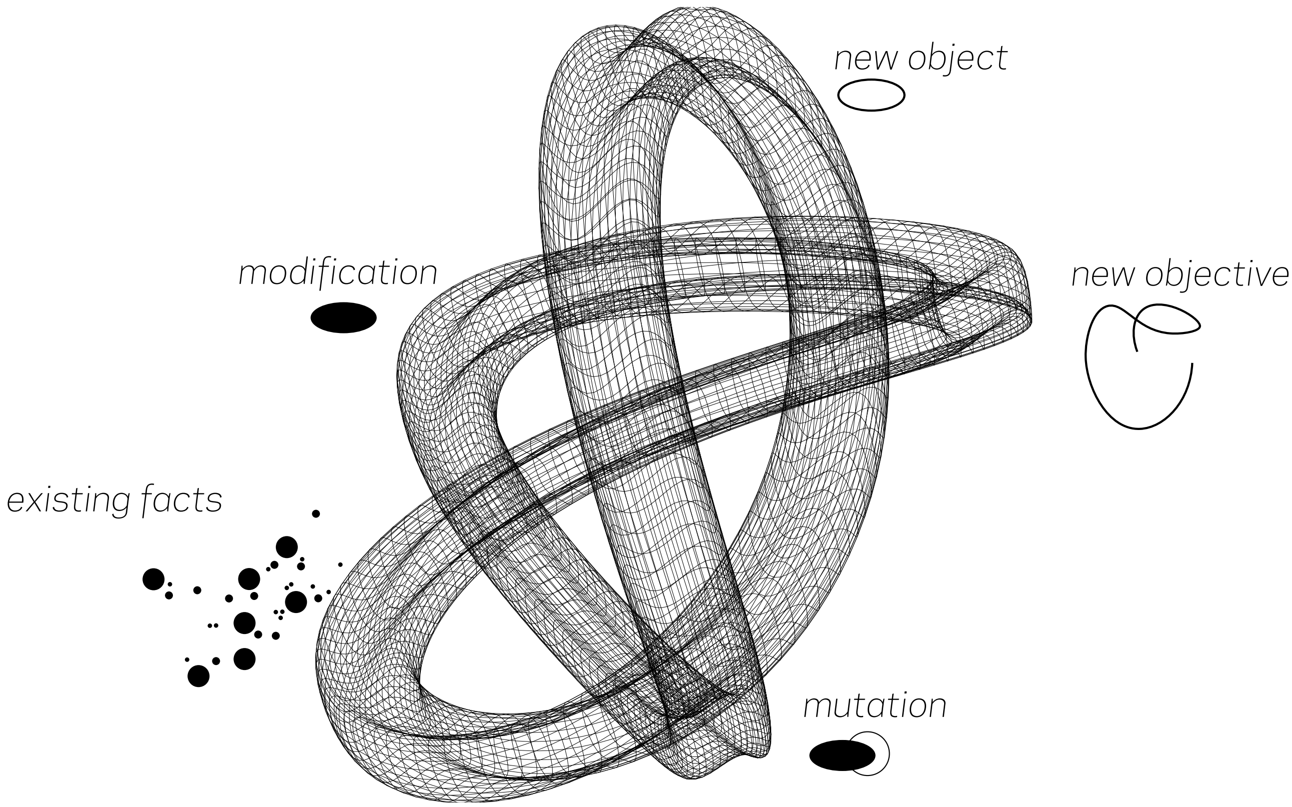

Figure: Time of Quantum and Data, Karolína Kotnour

The prerequisite for the creation of *Architectural Intelligence* is the use of advanced computational methods and the application of models for the analysis and representation of large data sources that effectively process a massive volume of data in the form of *architectural intelligence algorithms*. These models can be applied and trained on a micro or macro scale in urban spaces, open landscapes or virtual environments. They allow you to work with all types of data on temperature, humidity, wind force, noise levels, precipitation, information on trends, behaviour, or biological feedback, moods in society and community influenced by human and cultural habits, tendencies and preferences of communities. The data entering the model are sensory or derived from extensive data collections and libraries, data emission atlases, etc.

The following chapters presents the main knowledge applied to the proposed architectural strategies representing advanced methods of data processing, encoding and decoding information. It outlines the use and verification of these strategies in physical and virtual space, with the application of analog and digital systems and architectures. It defines a novel architectural approach, the *Architectural Intelligence* that will allow to bridge the narrow boundary between the detailed analysis of input information from the environment, and the architectural design. With the processing of the data we move in "*a space where design and analysis were connected in a seemingly simultaneous moment. So we are collapsing the relationship between design and analysis*."[2]

Intelligence is encapsulated as a series of architectural entities capable of rewriting existing protocols, "thereby allowing one to challenge the long-standing inability of architecture to productively and creatively address acute issues to sustainability."[3] The truth of the matter is that it is simply a recalculation of a piece of code that produces an update. "This can generate an illusion of animation, but it has implicit a much more complex idea of time,[4] and nonlinear time becomes ubiquitous."[5]

The design approach encoded within model systems capable of negotiating fundamental architectural problems radically departs from the more simplistic use of *multi-agent systems* for the generation of e*mergent patterns* that act as templates for architecture. "For this mode of dissolving normative architectural hierarchies[6] we are able to rewire the conception of space from several different inputs"[7], enhanced Jose M. Sanchez and Andreas Schlegel in the interview for Perspecta on Processing Architecture from 2011 and reopens the powerful concept for architectural design approach of John Frazer from 1970 on evolutionary

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[2] Reas, C., & Fry, B. (2011). MOS, Processing Architecture. *Perspecta, 44*, 153-202.

[3] Reas, C., & Fry, B. (2011). A. Andrasek, Processing Architecture. *Perspecta, 44*, 153-202.

[4] Reas, C., & Fry, B. (2011). MOS, Processing Architecture. *Perspecta, 44*, 153-202.

[5] Reas, C., & Fry, B. (2011). Jose Manuel Sanchez, Processing Architecture. *Perspecta, 44*, 153-202.

[6] Reas, C., & Fry, B. (2011). Roland Snooks, Processing Architecture. *Perspecta, 44*, 153-202.

[7] Reas, C., & Fry, B. (2011). Jose Manuel Sanchez, Andreas Schlegel, Processing Architecture. *Perspecta, 44*, 153-202.

architectures and genetic algorithms. And further, already in 1970 Frazer highlight to distinct from traditional uses of geometry, the code allows us to rethink form at a more primitive and fundamental level, a level underneath form. *"This operative process below form has profound implications, radically inclusive, it allows for experimentation with media new to architectural creation and thus expands our understanding on how the architect can operate within the world, producing the new subjectivities and aesthetic possibilities."*[8]

The future architecture design and construction is established *"not on the death of culture or the incoherence of consciousness, but the revitalisation of our whole state of being and a renewal of the conditions and construction of what we choose to call reality"*[9], on the revitalisation and actualisation needed for every civilised culture to flexibly face the most challenging issues of the recent times.

[8] Reas, C., & Fry, B. (2011). MOS, Processing Architecture. *Perspecta, 44*, 153-202.

[9] Ascott, R. (1996) The Museum of the Third Kind, InterCommunication no. 15, 1996. URL: http://www.ntticc.or.jp/pub/ic_mag/ic015/ascott/ascott_e.html (retrieved 25 February 2020).

1.1 Motivation

The *complexity* of the *architectural language* can be found in the language of sound and its dynamic.[10] Sound is a unique form of energy that transports us to spaces that are far from us and invasively approach and create our reality, while "architecture mediates our relationship with the limitless cosmos, it situates and frames the habits, passions and potentials of human existence."[11]

This work aims to build a computational model of neuro-evolutionary algorithm driven architectures, where space matter particles and neural waves meet waves and particles of sound, and are uniformly revealed in quantum systems[12],[13] of logical structures, flows and fluid compositions.

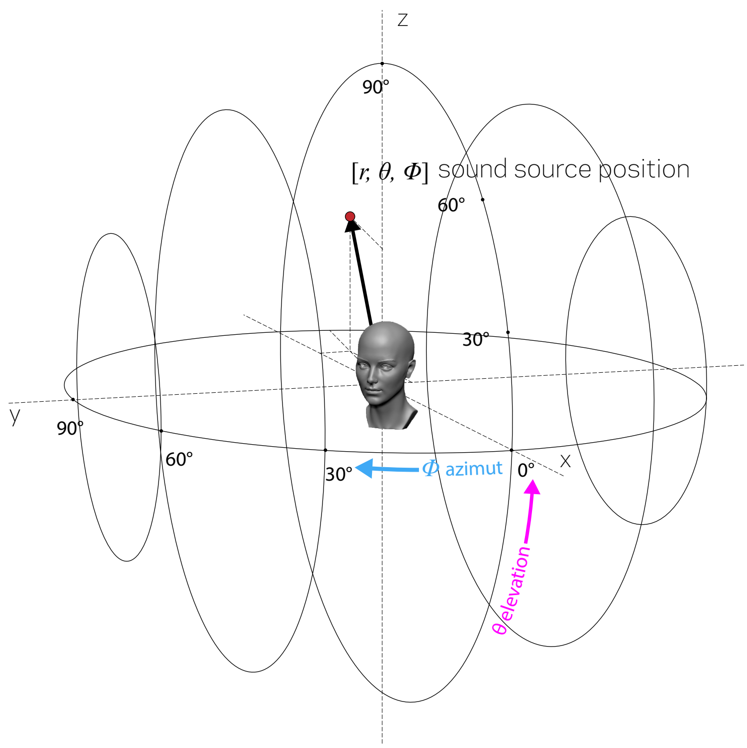

Figure: Ambisonic Sphere - Abstract Unit of Quantum based System by Karolína Kotnour

[10] Kotnour, Karolína, unpublished notes 2020

[11] Robinson, Sarah, and Juhani Pallasmaa. Mind in architecture : neuroscience, embodiment, and the future of design. Cambridge, Massachusetts: The MIT Press, 2015.

[12] https://www.insidescience.org/news/phonons-bring-good-vibrations-quantum-physicists

[13] https://virtualmarchmeeting.com/presentations/interfacial-effects-on-phonon-transport-in-quantum-sensors-for-dark-matter-detection

Architecture

From time immemorial, the idea of architecture has been a response to mastering the dynamics of the environment and the direction of flows and streams, taming of fluids, water, energy, sound, information. In these areas, architecture assumes competence and strives to stabilise these flows. At the same time, architecture, like nature, always seeks out and manages the ways of connecting individual elements, banks, cells, and uses the basic architectural principles replicated within the whole functional structure and mechanism forming the body and form of these architectures.[14] “All function and all forms are contained in the structure, as in the case of electricity, polarisation creates a nucleus of relationship.”[15] “The construction of all this is an art of making a meaningful whole out of many parts, and architecture, the art of joining. While sometimes it’s science and sometimes art, sometimes particle and at other a wave - more than a kernel or a shell, it can and must be everything: all at once. The work of art is judged not by the binary criteria of right or wrong, but by how it moves us - how it deepens us - how it opens new dimensions in our minds and unfolds new potential in our lives.”[16]

Body

The architecture is born of the body, and when we experience profound architecture we return to the body.[17] The task for architecture is to reinforce our sense of the real and trough doing that to liberate our senses and imagination. Architecture is an art of the body and existential sense. “A powerful architectural experience silences all external noise; it focuses attention on one’s very existence. Architecture, as all art, makes us aware of our fundamental solitude. Buildings and cities are instruments and museums of time. They enable us to see and understand the passing

[14] Hovestadt, L., online lecture, (2015). Coding Architecture

[15] Braham, W. W., Hale, J. A., & Sadar, J. S. (2007). Rethinking technology: a reader in architectural theory. London: Routledge, Taylor & Francis Group.

[16] Robinson, Sarah, and Juhani Pallasmaa. Mind in architecture : neuroscience, embodiment, and the future of design. Cambridge, Massachusetts: The MIT Press, 2015. p. 156.

[17] Robinson, Sarah, and Juhani Pallasmaa. Mind in architecture : neuroscience, embodiment, and the future of design. Cambridge, Massachusetts: The MIT Press, 2015.

of history, and to participate in time cycles that surpass the scope of individual life."[18] "Architecture connects us with the dead; through buildings we are able to imagine the bustle of the medieval street, and fancy a solemn procession approaching the cathedral. The time of architecture is a detained time; in the greatest of buildings time stands firmly still. As in the narrative frames wrapped in peristyles of The Temple of Hathor in Dendera, time has petrified into a timeless present; time and space are eternally locked into each other between these immense columns."[19]

Life

The main motivation of architectural thought and creation, as it was always understood, is to preserve all manifestations of life. Life is the most obvious example of an evolving process, defined as " a state of functional activity and continual change peculiar to organised matter, and especially to the portion of it constituting an animal or plant before death, animate existence, being alive".[20] Architecture is a tool for ensuring the generation and regeneration of life and structures physical, emotional, mental and social well-being.[21],[22]

Sound

The proposed comptational models and strategies of evolutionary architectures and representations of the dynamic environment of soundscapes are inspired by radical music and related artistic approach resulting from the Musique concrète movement in Paris around the composer Pierre Schaeffer, further developed by Pierre Boulez, Karlheinz Stockhausen, György

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[18] Pallasmaa, Juhani, Touching the World – Vision, Hearing, Hapticity and Atmospheric Perception Invisible Places 2017 Proceedings of Invisible Places Sound Urbanism and Sense of Place. Edited by Raquel Castro & Miguel Carvalhais. ISBN 978-989-746-129-3. 15-28 pp. http://invisibleplaces.org

[19] Pallasmaa, Juhani, Touching the World – Vision, Hearing, Hapticity and Atmospheric Perception Invisible Places 2017 Proceedings of Invisible Places Sound Urbanism and Sense of Place. Edited by Raquel Castro & Miguel Carvalhais. ISBN 978-989-746-129-3. 15-28 pp. http://invisibleplaces.org

[20] Oxford English Dictionary, in the Concise Oxford English Dictionary (1983)

[21] Kiesler, Frederik, Manifest de Correalismé, 1948

[22] Robinson, Sarah, and Juhani Pallasmaa. Mind in architecture : neuroscience, embodiment, and the future of design. Cambridge, Massachusetts: The MIT Press, 2015.

Ligeti, Edgar Varése, Iannis Xenakis and later developed and strengthened by progressive musicians and artists up to contemporary music and radio art. At the same time, an emerging musical style was established - Noise (~ Šum) performed by several artistic manifestos by Luigi Russolo. Noise, with the advent of computers, came to digital music synthesis and generative computer music based on the randomness of numbers over time.

The Future Architecture

The architectural approach reflect the available technologies in terms of spatial design, and to take into account the body and its physical, emotional, mental and social dimensions. The architecture augment the human capabilities or decrease limitations. In complex dynamic environments evolve as adaptable accommodable and assimilable entity. *Neuro-evolutionary architectures* may be the answer to the motivation. The meaningfulness of architectural intelligence is understood in its impermanence yet resilience and portability, and the possibility of autonomous self-assembly, self-organisation, self-maintenance and self-replication of an effective mutations. The architecture benefits from the compositional and methodological parallels between computer science and advanced architecture design.

The need and motivation that determines human existence, is communication and movement. The same motivation and need urge to constantly reshape the spatial hierarchies of the natural environment and transform it into a technological and artificial environment that evolves in continuous mutations. Processes determined by technologies, creative and intellectual activities of the individual, intervene in all layers of the *architectural environment*.

The quality of space is given by the ability to communicate and demand to communicate and understand.[23] The resulting architecture should be able to flexibly meet these requirements and communicate them. The impulses of the environment are activating an evolutionary mechanisms and processes within its inherent architectural articulations.

[23] Licklider, J.C.R. 1960, 'Man-Computer Symbiosis', n-IRE Transactions on Human Factors in Electronics, 1, pp. 4-11 LICKlider, J.C.R. 1968, 'The Computer as a Communication Device', Science and Technology, 76, pp. 21-31

Figure: Tensor field displayed with ellipsoids (left) and tracked fibers (right)

Research Problem

This thesis and proposed architectural approach, directs forces and energies, not objects, "not circumscription of a solid but a deliberate polarisation of natural forces towards a specific human purpose."[24] The future of building and architecture are in *multilayered interconnections* between technology, nature and man, and approached with interdisciplinary scientific domains. The architecture always been a multilayered domain and the challenges such as finding the

[24] Braham, W. W., Hale, J. A., & Sadar, J. S. (2007). Rethinking technology: a reader in architectural theory. London: Routledge, Taylor & Francis Group.

architectural articulation between man and artificial, man and technological or digital environment is an essential quest of future architecture in every aspects.

The research problem is to build a digital platform to visually communicate architectural articulation of relation between human and dynamic environmental conditions and trace behavioural and perceptual balance patterns. This thesis research techniques and proposes a digital tool and creative assistant for architects, a software that provides an insight to the invisible flows of energies, effectively distributed in a meta-space and allows observation of physical qualities that correlate with the human behaviour and perception.

1.2 Main Claims and Research Questions

Digital technologies and communication media have recently been used more and more in all areas of human activity, in digital architecture we are experiencing the same trend and a new challenge for advanced design methods. In the field of architectural creation, adaptation to the technological world is very methodical. New digital tools and new approaches to architectural creation are being accepted with generally great apathy. The transition from tools that have been used for several decades to new tools is facing great difficulties.

In the 21st century, we are experiencing the development of new approaches to analysis, primarily influenced by the possibilities of immediate optimisation of applied and validated knowledge, defining a more accurate and finer boundary between established and validated schemes. These schemes alone are not able to respond dynamically to the ever-changing needs of people, entire communities and the entire ecosystem of the human environment, which adapt to new situations and evolve. Digital architectural creative approaches are dynamically evolving and using their own digital tools and software, thus radically changing the concept of the architectural design process.

From the very beginning of defining the architectural strategy for a given environment, state or situation, we use digital tools to verify the first prototypes. These prototypes are written in scripts and powerful generative models, probability estimation networks, evolutionary architectures, as a methods of architectural intelligence. The process of design and fabrication is synthesised in a spike of information transmission.

The architectural intelligence is a quantum based model that works with meta-material, that consist of qubits, which accurately and efficiently places in a digitally composed architecture. These architectures, are designed with environmental qualities and environmental capabilities in mind, so they perceive and respond together to the complexity of the environment. In the properties of virtual materials, the basic mechanisms are encoded to be able to respond empathetically and instinctively and understand the behaviors and needs of the population or human individual and changes in the environment and effectively unify them into a functional architectural expression.

Neuro-biofeedback

Recently, we have a deeper knowledge of brain activity and cognitive processes in the human brain. We have learned from biological data that similarities and patterns can be detected in our brain activities. From the progressive field of artificial intelligence, which is based mainly on reverse engineering, we benefit from effective models of deep learning to understand natural processes and understand patterns of human behavior and perception.

Claims

By developing AI based on a neuro-evolutionary generative algorithms and architectures, with acquired biopsychological parameters of behavior, we will enable people to connect and communicate with architecture, and modify its spatial requirements.

The sound composition captured in the code, where the basic element of sound, the sound granules, are precisely controlled, represents the spatial distribution of the basic elements of the encoded virtual materials, architectected meta-structures. The architectural space consist the internal and external environmental forces, and human perception is to provide an interactive and attentive feedback on both sides. The environmental pressure investigated in this thesis is sound and noise masses.

Sound is a form of energy that can be easily and very accurately spatially focused. In addition, in a digitally controlled environment, we control its frequency, density, volume and position in space.

Main Research Questions

What does a computer system need to know about the environment and the human user in order to *understand* the human experience?

What computational models are used to process the dynamic forces of the environment, and what are appropriate to integrate into architectural spatial models?

How to build a system of machine learning algorithms that controls the self-balancing tendency based on behavioural and environmental adaptations?

How to display and visualise trends and directions of *Meta Architecture* organisation?

How does the computer system interfere with the intelligent environment to improve it?

The experimental work and research brought up many technical and theoretical questions along the framework of Complex Environment Model and Neuro-evolutionary Architecture algorithm concepts. While some of the solutions are integrated in the model of Meta-Evolver, partially they will remain for a further research, and the quest for the next generation of computing, and powerful quantum computers.

Secondary Research Questions

How to cope with large data volumes and extreme computational demands of machine learning algorithms?

How to solve communication between machine learning algorithms and platforms, PureData, SuperCollider, EEG NeuroCap, with 3D visual game engine for display and visualisation?

How to display and visualise complex spatial sound patterns and define the edges and predominant directions of trajectories of self-evolving architectural meta-material?

What machine learning models are suitable for processing dynamic multidimensional force fields of the environment that can be integrated into a digital tool for spatial representation and their architectural articulation?

What are the current computational models, programming languages, and models of machine learning and artificial intelligence algorithms that can be applied to a digital architectural model.

Can we use these algorithms to achieve a self-balancing environment and its architectural articulation based on the behaviour of one or more individuals?

How to maintain the modularity of the whole system so that for further work it is possible to make changes both in the machine learning algorithms and in the monitored parameters and to enable the extension and adaptation of the model in the future?

Coded Architecture

This work outlines the compositional principles in the architectural process of the search for form, triggering forces, environmental factors and spatial adaptation strategies.

The sound is the form of energy that can be easily and very precisely spatially targeted. Moreover its density and volume can be controlled in space.

Could be achieved through architectural programming language a balanced environment for individuals and communities based on their experience of space and specific cultural and social behaviour?

Intelligent technologies are able to take into account the psychology and *behavioural patterns* of individuals, buildings that adapt not only to the environment and provide ideal conditions and climate for their functionality, but also architectures that reflect and communicate with individuals and connect with us. This work predicts a strong bond between man and technology, and proposes a close Human-Architecture Symbiosis, which creates dynamic environments and architectures that take on human qualities and perceptions.

1.3 Main Research Goals

The main research activities are of the construction and testing of artificial intelligence algorithms (AI), evolutionary algorithms and artificial neural networks (ANN), successful in the classification and clustering of an input data. Secondly testing and examining the outputs of algorithms that find patterns, tame mutations, and support successful evolution.

The research goal is to define an *Architectural Intelligence* based on the multiple dynamic aspects, behavioural and environmental forces, defined as algorithm parameters and instance features.

The negotiated *Architectural Intelligence* in this thesis is based on spatial environmental dynamic force - sound, and its complex spatial compositions - soundscapes of the environment.

The Neuro-Evolution is proposed as a form of Architectural Intelligence that learn, assume and predict behaviour on neural basis from the neuro-bio-feedback, spikes of neurones in a human brain activity reacting on a spatial sound stimuli. The *Architectural Intelligence system* for an complex dynamic environments is based on coded architecture models and multilayered systems.

In order for *Architectural Intelligence* to capture the complexity of the real world, it must include in-depth control and knowledge of large databases of dynamic data. Above all, the architecture should provide new strategies for data collection and processing, the construction of learning models and knowledge transfer, in order to effectively apply what is already known and inform the design to be created.

The qualitative and quantitative parameters of dynamic data is crucial to develop ambitious projects, which crucially creates articulated entities, not as a representation of complexity but as the solution for complexity.[25] The current and still evolving stage of digitalisation applied to architecture demonstrates to us that digital tools are useful to explore a potentially unlimited number of design solutions in order to find the best solution to a specific problem. The design project does not find its essence in defined specific goals but it is the outcome of a process in which a new forces enter, and was impossible to describe and control them so far.

The inspiration and the guidelines of the design intent are no longer collected from the rules of an architectonic tendency or from artistic influences but their reasons are now found in sets of dynamic data gathered from the environment. This not only refer to a one to one scale built environment but primarily to the realm in which physical forces, structural strain and stresses, or the molecular properties of materials exist that carry out their functions.[26]

Algorithmic design is not simply the use of computers to design architecture and objects. Algorithms allow designers to overcome the limitations of traditional CAD software and 3D modellers, reaching a level of complexity and control which is beyond the human manual ability.[27]

Spatial Representation and Configuration of a Model

[25] Springer International Publishing AG 2018 M. Hemmerling and L. Cocchiarella (eds.), Informed Architecture, The Algorithms-Aided Design (AAD), Arturo Tedeschi and Davide Lombardi. DOI 10.1007/978-3-319-53135-9_2

[26] Springer International Publishing AG 2018 M. Hemmerling and L. Cocchiarella (eds.), Informed Architecture, The Algorithms-Aided Design (AAD), Arturo Tedeschi and Davide Lombardi. DOI 10.1007/978-3-319-53135-9_2

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Those dynamic physical forces, in a proposed model, that produce a form, are sound waves and noise masses, our body motion trajectories, our brain activity, our behaviour. Brain performance is recognised as a unique sequence of dominate waves that evolve over time. With these dynamic data fields and their features, computational model work as a with a virtual material. The architectural neuro-evolution algorithm is able to evaluate the optimal configuration for a given situation and environment. The dynamic data fields entering the algorithm, are processed and features and parameters are extracted for the chosen evolutionary strategy. Based on these functions, features and parameters, the algorithm generates unique architectural articulations of the physical and behavioural force fields.

Design Hypothesis

To capture and integrate dynamic power, sound, we need a form of Architectural Intelligence as a set of evolutionary mechanisms that are able to learn and adapt to the dynamic situation of the external environment or changes in human behaviour.

The Architectural Intelligence is a set of evolutionary mechanisms that has capability to adapt architectural organism to the dynamical environmental or behavioural situation.

The Architectural Intelligence is both adapting, changing and accommodating the dynamic of the environment.

Scientific Hypothesis

The Meta-Learning approach along with the Neuro-Evolution algorithms of the large scale neural networks provide effective intelligent model for a continuous adaptation in a dynamic complex environments.

1.4 Secondary Research Goals

The secondary goal is to contribute with a novel architecture thinking to a common ground of multidisciplinarity, future emerging technologies and computing and not least to the *Computer Aided Architecture Design approach*.

Test *Advanced Computer Music Methods* for architectural intelligent systems, and their applicability for computing architectural structures, meta-materials, or neuro-evolutionary architectures.

Define a methodology for processing a relevant multidimensional data from the environment for a digitally composed and maintained architectural models in a complex environments.

This research consider recent methods and technologies in *Human-Brain-Compuuter*—Interaction (Neuro-biofeedback Wearables, Human Biofeedback, BCI, Human Computer Interaction) and establish their position in the context of human interaction with physical environment and architectural immersive, attentive and augmented spaces. Further context is related with speculative polemical theories on *Transhuman Entities*, and Augmented Sensorium Modulor.[28] Review recent technologies and formulate the demands on domain of Brain-*Computer Artificial Intelligence Architecture*, and *Architectural Intelligence*.

The augmented architectural space, virtual reality spaces, *Meta-Spaces* and *Metaversum* are advancing the physical architectural space and the intelligent environmental and architectural models should bear in mind increasing demands on the *Architectural Time Non-Linearities*.

1.5 Architectural Approach

The status of architecture is on search for an architectural language that can communicate the recent technological world and world of information. This thesis propose to approach architectural language that comes along, with code writing, and composing of code scripts that evolves and rewrite its own concepts and protocols - coded *Neuro-Evolutionary Architecture* algorithms. This architectural approach is suggesting a mathematical language written in a scrips, and dynamic code. The fundamental topological definitions and characteristics of an objects, topological formulas, are developed by a set of evolutionary algorithms and system of trained neural networks that modify a given parameters in to a several super-parameters and adapt them into the balanced organisation.

This research is concerning an evolving architectures that are triggered by sound frequencies, and designed and formed in a constant process of change and transformation as a *Neuro-*

[28] Kotnour K., Short Paper, DCC'18 poster panel

Evolution Architecture. The genetic algorithms combined with neural networks with features of sound and space literally synthesise them in an *hyper-real architectural articulation* that is capable of reflecting a human behaviour, and perception and this way enhance their interaction and experience of immersion in architectural body.

Coded Neuro-Evolutionary Architecture

The quests for advanced architecture lays in encoding and decoding the external and internal environmental and behavioural forces by attentive and adaptive architectural intelligence, lays in the impermanence, in the immersion, on the edge of actual and virtual. The main quest lays in the negotiation between human intelligence and machine intelligence where human intelligence is defining what is the problem and machine intelligence is suggesting how this problem should be solved.

The research and experimental projects were driven by several motivations, first one, is the interconnection of architecture with human, the physical and psychological behaviours, distinctiveness and levels of perception, where architecture is an optimised expression of a mental space. The second motivation and theoretical problem is a demand on effective distribution of an energy and matter in space, directing an force fields and flows in an architectural expression, that was investigated through the abstract work and experiments with spatial sound and dynamic force fields in digital model of dynamic environment.

Most of the man-made and built environments have incomplete and simple structures: they do not recycle their materials, are not adaptable, and they waste energy.[29] This research is approaching this problem and looking for possibilities and potentials that are driven by search for novelty in the domain of artificial intelligence and it's application in architectural creation.

Architectural Intelligence

I worked with various types of Artificial Neural Networks, Convolutional Neural Networks (CNN), Generative Adversial Networks (GAN), Self-Organizing Maps (SOM), Auto-encoders,

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[29] Frazer, John. *An evolutionary architecture*. London: Architectural Association, 1995.

Transformers, CPPN and NEAT Compositional Pattern Producing Networks and Neuroevolution of augmenting topologies and experimented on different approaches for machine perception, such as image recognition, computer vision, and audition, intelligent creative composers, style transfer machines. More over by integrating evolutionary algorithms in to the process of learning and adaptation I

Imperative Computing Infrastructure

Within the past years there are more powerful machine learning models and better access to a cloud computing units and other alternative computing domains for large scale model computing. At the Department of the Architectural Modelling, MOLAB, is now accessible GPU nest for the remote computing and rendering. Therefore due to lack of computing performance should be developed the branch for the MOLAB, Faculty of Architecture with the user friendly UI, from the MetaCentrum, National Grid Infrastructure (NGI) for massive computations, that has been use remotely for prototype computing and training. The main part of the progressive computation in this experimental works was made on the Googles virtual GPU, that is easily accessible through Google Colaboratory.

This research is explored through:

- code prototyping
- neural networks composing
- virtual environment modelling and testing
- experimental audio-visual work and installations (interior, exterior)
- human brain computer interaction
- lecturing and workshops
- scientific publications

"For beauty is nothing but the beginning of terror which we are barely able to endure, and it amazes us so, because it serenely disdains to destroy us.
Every angel is terrible."

Reiner Maria Rilke, Duino Elegies, 1923

1.6 Definition of Research Fields

The work presented in this thesis is the result of intense multidisciplinary research ranging from Neuroscience, Cybernetics and Computer science, Sound Art and Music Technology and Composition, Architecture and Philosophy, synthesised in novel approach in architectural thinking. These domains and their sub-domains are connected in a scientific field called Cognitive science. Where the main motivation is joining the architecture with human behaviour and perception processes in a dynamic environment. The exploration in these domains, architectural design, cognitive science and human computer interaction, builded on the mathematical models and algorithms of machine learning, revealed only a fragment of the whole field of complex architectural systems, while there are still number of technical and philosophical problems to be discussed and solved before the long time perspective and main goal where the Architectural Intelligence perform inhabitable environments, is achieved.

Cognitive Science

"The relationship of scenic details, their capacity for association, creates from the abstract and undefined space of the stage a transformable, kinetic, dramatic space and movement. Dramatic space is psycho-plastic space, which means that it is elastic in its scope and alterable in its quality. It is space only when it needs to be space. It is cheerful space if it needs to be cheerful. It certainly cannot be expressed by stiff flats that stand behind the action and have no contact with it."

Josef Svoboda, Theater Artist in an Age of Science,

"Scena v diskusi", Divadlo, May 1963

Cognitive science is the interdisciplinary study of mind and intelligence, embracing philosophy, psychology, artificial intelligence, neuroscience, linguistics, and anthropology. Its intellectual origins are in the mid-1950s when researchers in several fields began to develop theories of mind based on complex representations and computational procedures. The central hypothesis of cognitive science is that thinking can best be understood in terms of representational structures in the mind and computational procedures that operate on those structures. While there is much disagreement about the nature of the representations and computations that constitute thinking, the central hypothesis is general enough to encompass the current range of thinking in cognitive science, including connectionist theories which model thinking using artificial neural networks.[30]

The field of cognitive science gave rise of Neuro-Evolutionary Architecture. Neuro-Evolutionary Architecture with addition of wearable devices, and wireless sensors that track movement, visual attention, and concurrent electroencephalographic (EEG) brain responses may reveal the association between neuro-bio-feedback and specific design features. These objective and subjective survey data, may reveal the design “as used” rather than “as built” and inform research-based design guidelines.

Mind and Machine

In 1986 in the book The society of mind Marvin Minsky, the cognitive scientist concerned with research on artificial intelligence and philosophy, is questioning him self: Are People Machines? Regarding Minsky, the first intuitions about computers came from experiences with machines of the 1940s, which contained only thousands of parts. But a human brain contains billions of cells, each one complicated by itself and connected to many thousands of others. Present-day computers represent an intermediate degree of complexity; they now have millions of parts, and people already are building billion-part computers for research on Artificial Intelligence.[31] And he adds: “And yet, in spite of what is happening, we continue to use old words as though there had been no change at all. We need to adapt our attitudes to phenomena that work on scales never before conceived. The term "machine" no longer takes us far enough. But rhetoric won't settle anything. Let's put these arguments aside and try instead to understand what the vast, unknown mechanisms of the brain may do. Then we'll find more self-respect in knowing what wonderful machines we are.[32] The human machines that operates and performs with billions of connections of brain and body cells on a basis of natural computation. Regarding Dana Ballard the central ideas of natural computation can be understood in terms of the composition of five

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30 Thagard, Paul, "Cognitive Science", The Stanford Encyclopedia of Philosophy (Winter 2020 Edition), Edward N. Zalta (ed.), URL = <https://plato.stanford.edu/archives/win2020/entries/cognitive-science/>.

31 Minsky, Marvin. *The society of mind*. New York: Simon and Schuster, 1986.

32 Minsky, Marvin. *The society of mind*. New York: Simon and Schuster, 1986.

basic mathematical and computational ideas: fitness, programs, data, dynamics, and optimization.[33]

Many contemporary scientists are not comfortable to talk about mental states. To look on the mental states is too subjective to be scientific, and it is preferred to base theories of psychology on ideas about information processing. As Bever mentions in his article, this has produced many good theories about problem solving, pattern recognition, and other important facets of psychology, but on the whole it hasn't led to useful ways to describe the workings of our dispositions, attitudes, and feelings.[34]

So far as consciousness is concerned, we find it almost impossible to separate the appearances of things from what they've come to mean to us. But if we cannot recollect how things appeared to us before we learned to link new meanings to those things, what makes us think we can recollect how we ourselves appeared to us in previous times? We all experience that sense of changelessness in spite of change, not only for the past but also for the future, too! Consider how you are generous to future self at present self's expense. Today, you put some money in the bank in order that sometime later you can take it out. Whenever did that future self do anything so good for you? Is "you" the body of those memories whose meanings change only slowly? Is it the never-ending side effects of all your previous experience? Or is it just whichever of your agents change the least as time and life proceed?

Marvin. Minsky, The society of mind New York: Simon and Schuster, 1986.

The Cognitive Neuroscience of Music

In terms of cognition of sound, granules and contours, tones, the traditional view of a left–right dichotomy of brain organisation, assuming that in contrast to language, music is primarily processed in the right hemisphere, was challenged 20 years ago, when the influence of music education on brain lateralisation was demonstrated. Modern concepts emphasise the modular organisation of music cognition. According to this viewpoint, different aspects of music are processed in different, although partly overlapping neuronal networks of both hemispheres. This simple viewpoint—still represented in many textbooks—could not be held any longer, when in

[33] Ballard, Dana H. - An Introduction to Natural Computation-MIT Press (1997)

[34] Minsky, Marvin. *The society of mind*. New York: Simon and Schuster, 1986.

1974 Bever and Chiarello[35] were able to demonstrate the influence of professional training on hemispheric lateralisation during music processing, non-musicians exhibiting right, professionals left hemispheric preponderance. It was assumed that professional musicians had access to different cognitive strategies ascompared to amateurs and nonmusicians.[36] These operations act interdependently in some parts, independently in others. They are integrated in time and linked to previous experiences with the aid of memory systems, thus enabling us to perceive, or better, to “feel” a sort of meaning while listening. Neuro-musicology has been profoundly influenced by the idea of the modularity of musical functions.[37] [38]

The connection between brain activation and musical perception is becoming clearer as more and more refined techniques become available to image neural activity. Brain imaging can be performed while subjects are listening to music or imagining it. One can measure the immediate correlates of music as well as its effects on brain development and later brain organisation.[39]

The perceptual relations among sounds equated for pitch, duration, and loudness are represented mathematically as a multi dimensional space. Timbral intervals are defined as oriented vectors in the space and timbral contours could be defined by the relative patterns of up and down along the various dimensions. A transformation of a timbre melody such as transposition would simply be the translation of the timbre vectors in the space, keeping their lengths and orientations constant. Although the precise reproduction of timbral intervals is problematic with insert mental music, such musical structures are quite possible with synthesised sounds.[40]

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35 Bever, T. G. and R. I. Chiarello (1974) Cerebral dominance in musicians and non-musicians. Science 185, 537–40.

36 Peretz, Isabelle, and Robert J. Zatorre. *The cognitive neuroscience of music*. Chapter 22, How Many Music Centres are in the Brain, page 346, Eckart O. Altenmuller. Oxford New York: Oxford University Press, 2003.

37 Fodor, G. A. (1983) The Modularity of Mind. Cambridge, MA: MIT Press.

38 Gardner, H. (1983) Frames of Mind. The Theory of Multiple Intelligences. New York: Basic Books.

39 Peretz, Isabelle, and Robert J. Zatorre. *The cognitive neuroscience of music*. Chapter 23, Functional Organisation and Plasticity of Auditory Cortex, page 357, Rauschecker, Josef P.. Oxford New York: Oxford University Press, 2003.

40 Peretz, Isabelle, and Robert J. Zatorre. *The cognitive neuroscience of music*. Chapter 6, The Roots of Musical Variation in Perceptual Similarity and Invariance, page 79, McAdams, Stephen, Daniel Marzkin. Oxford New York: Oxford University Press, 2003.

The connection between brain activation and musical perception is becoming clearer as more and more refined techniques become available to image neural activity. Brain imaging can be performed while subjects are listening to music or imagining it. One can measure the immediate correlates of music as well as its effects on brain development and later brain organisation.[41]

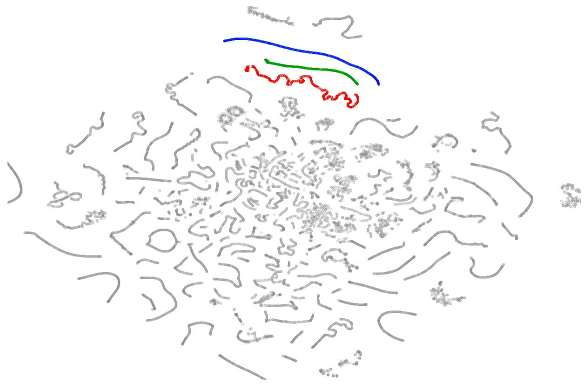

Figure: Tatar, K., Bisig, D., & Pasquier, P. Latent Timbre Synthesis: Audio-based Variational Auto-Encoders for Music Composition Applications. The Special Issue of Neural Computing and Applications: "Networks in Art, Sound and Design."https://doi.org/10.1007/s00521-020-05424-2

Computer Science

Computer Science encompasses theoretical ideas about how information is stored and processed and how we can express the instructions necessary to perform a useful computation. It is also about practical techniques for the creation of new computer software and hardware. Computer Science requires logical thinking, creativity and problem solving.[42] Computer science is the study of algorithmic processes, computational machines and computation itself. As a discipline, computer science spans a range of topics from theoretical studies of algorithms, computation and information to the practical issues of implementing computational systems in hardware and software.[43],[44]

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41 Peretz, Isabelle, and Robert J. Zatorre. *The cognitive neuroscience of music*. Chapter 23, Functional Organisation and Plasticity of Auditory Cortex, page 357, Rauschecker, Josef P.. Oxford New York: Oxford University Press, 2003.

42 "What is Computer Science? - Computer Science.The University of York". *www.cs.york.ac.uk*. Retrieved June 11, 2020.

43 Wordnetweb.princeton.edu. Retrieved May 14, 2012. http://wordnetweb.princeton.edu/perl/webwn?s=computer+science

44 "Definition of computer science | Dictionary.com". *www.dictionary.com*. Retrieved June 11, 2020.

Computation is described by what a Turing machine can do. If you want to show that the brain is not a computer, the way to go about it is to demonstrate something that the brain does that cannot be reduced to a Turing machine program. There have been several attempts to do this, but so far they have not carried the day. The nature of Turing machines is that they can only represent integers. Real numbers, random numbers, and predicate logic must therefore be approximated. [45]

Human Computer Interaction

The human-computer interaction (HCI) spans a broader range of disciplines and their combinations. It is complex because it borrow research methods from a number of different fields, modify them, and create new standards for what is considered acceptable research. It is also complex because this research involves complex systems - humans. The experiment implemented in this research employs apply human-computer interaction field to develop and modify digital architecture models, evaluate and verify different design solutions, and answer various other critical questions, such as technology adoption in architectural environment.

Technology also implies a transcendence of the materials used to comprise it. In 1875, the transcended materials for the first time, enabled that a human voice was transported, magically it seemed, to a remote location. Most assemblages are just that: random assemblies. But when materials - and in the case of modern technology, information - are assembled in just the right way, transcendence occurs. The assembled object becomes far greater than the sum of its parts.[46] Man-computer symbiosis is an expected development in cooperative interaction between human and computers in not too many years, human brains and computing machines will be coupled together very tightly, and that the resulting partnership will think as no human

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[45] Ballard, Dana H. *Brain computation as hierarchical abstraction*. Cambridge, Massachusetts: The MIT Press, 2015.

[46] Kurzweil, Ray. The age of spiritual machines : when computers exceed human intelligence. New York: Viking, 1999.

brain has ever thought and process data in a way not approached by the information-handling machines we know today. [47]

Since the 60s, intelligence has started to become a matter of concern in HCI. Due to their increasing capabilities and autonomy, interactions with computers changed, as they transformed from being "tools" to becoming "agents". Generally speaking, agents are entities that can function autonomously without human intervention, and that can interact with other agents including humans. [48]They are further able to log, sense and collect data, perceive their environment, and react to changes in a timely fashion.[49] Licklider proposed a new perspective on human-computer interaction, that he named human-computer symbiosis, to better understand the new opportunities and challenges when interacting with computers as an actors. The role of the computer has shifted from the execution of automated tasks that are predefined by humans to the formulation of these tasks and their collaborative approach to these complex assignments as partners of human experts.

When AI was developed in the context of virtual assistants, people continued to think about what it would be like when agents will be able to help us do things and augment our abilities[50]. The main challenges foreseen by Norman were related to the social ability of such agents concerning the ways they interact with other agents and humans. The ongoing development and increased possibilities of computational technologies do call on designers to add another design resource and material in their toolkits, which is intelligence.[51] Designing with materials usually requires particular skills and knowledge that enable designers to work with the material and explore its opportunities and limitations. These involved having an accurate understanding of the nature and use of ML, how to prototype it, and how to purposefully design with it. This recent view on intelligence as a design material discusses some of the required skills and knowledge. For

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[47] Licklider, J. C. R. IRE Transactions on Human Factors in Electronics, volume HFE-1, pages 4-11, March 1960

[48] Filimowicz, Michael & Tzankova, Veronika. (2017). New Directions in Third Wave Human-Computer Interaction Volume 1: Technologies.

[49] Wooldridge, M. and Jennings, N.R. (1995) Intelligent Agents: Theory and Practice. The Knowledge Engineering Review, 10, 115-152. http://dx.doi.org/10.1017/S0269888900008122

[50] Norman DA (1994) How might people interact with agents. Commun ACM 37(7):68–71

[51] Holmquist LE (2017) Intelligence on tap: artifcial intelligence as a new design material. Interactions 24(4):28–33

instance, developing an appropriate technical understanding of AI and ML, and ways to program it.[52] Rather than understanding and applying AI as technical instrumentation, this research is suggesting to understand how artificial intelligence can meaningfully be employed within form-finding models in architecture design and HCI.

Neuroscience

The irreversibility of computation is often cited as a reason that computation is useful: It transforms information in a unidirectional, "purposeful" manner. Yet the reason that computation is irreversible is based on its ability to destroy information, not to create it. The value of computation is precisely in its ability to destroy information selectively. For example, in a pattern-recognition task such as recognising faces or speech sounds, preserving the information-bearing features of a pattern while "destroying" the enormous flow of data in the original image or sound is essential to the process. Intelligence is precisely this process of selecting relevant information carefully so that it can skill-fully and purposefully destroy the rest.[53]

Increasingly, we are starting to combat cognitive and sensory afflictions by treating the brain and nervous system like the complex computational system that it is. Cochlear implants together with electronic speech processors perform frequency analysis of sound waves, similar to that performed by the inner ear.

The brain is nothing like a conventional computer and is staggeringly more complex, even though at an abstract level the brain has to solve some of the same kinds of problems. Nonetheless, the huge number of differences between silicon circuits and neurobiological structures means that the biological solutions must be of a hugely different character.[54]

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[52] Rozendaal, Marco & Ghajargar, Maliheh & Pasman, Gert & Wiberg, Mikael. (2018). Giving Form to Smart Objects: Exploring Intelligence as an Interaction Design Material. 10.1007/978-3-319-73356-2_3.

[53] Kurzweil, Ray. The age of spiritual machines : when computers exceed human intelligence. New York: Viking, 1999.

[54] Ballard, Dana H. *Brain computation as hierarchical abstraction*. Cambridge, Massachusetts: The MIT Press, 2015.

The major factor separating silicon and cells is time. The switching speed of silicon transistors, which limits the speed at which a processor can function, is in the nanosecond regime. In contrast, neurons send messages to each other using voltage pulses or,“ spikes.”[55]

In an analogous way, the neural spike code can be a sparse discrete code; the body makes the music.

Although we still do not quite know how to specify the brain ’ s processors in detail, we suspect that nerve cells will be at the center of the answer. So the method is to define models of neurons that represent best guesses of what is important about them and then define algorithms that use these abstractions. When one starts to do this, one quickly finds out that the brain ’ s algorithms must be very unlike those for conventional silicon computers.

This difference is most apparent when considering the standard way of evaluating algorithms, and that is to see how long they take to complete. But even this measure must be changed for brain algorithms. For silicon processing, the traditional way of counting operations is called “ worst case. ” We want to guarantee that the algorithm will take no longer than some temporal bound. But the brain doesn ’ t care about the worst case because it is always under time pressure. If something is taking too long, there is always the option of giving up and moving on. And in this spirit, the brain also uses lots of dramatic economies. Let ’ s introduce the main ones.

One difficult problem the brain has is to slice and dice the continuous nature of sensory motor commerce into a form that can be interpreted by internal codes. The frequency that demarcates the beginning and end of such an episode is the θ (theta) frequency. For humans, the length of an episode can be arbitrary, say as in planning a long trip. For more near-term behaviors that involve real-time control of the body, such as reaching for a coffee cup on a nearby table, evidence suggests that the β (beta) frequency is used.

[55] Ballard, Dana H. *Brain computation as hierarchical abstraction*. Cambridge, Massachusetts: The MIT Press, 2015.

Furthermore, the computing machines, tied with silicon, these machines have evolved to augment human needs rather than exist on their own and as such have not been made to exhibit the kinds of values inherent in biological choices.

Hierarchical Brain Organization

Just like any complex system, the brain is composed of distinct subparts with specialized functions. To propose good computational models, it is essential to understand what these parts do. The brain ' s forebrain, which is the site of neural algorithm development and storage, draws heavily from primal abstractions discovered by evolutionarily earlier brain areas.

Computational Abstraction Levels

An essential take-home lesson from complex systems is that they are inevitably hierarchically organized. This means that to understand the brain, it is necessary to integrate algorithms at several different levels of abstraction. Abstraction levels in brain anatomy and in silicon computers are accepted, but abstraction levels for the brain ' s computational algorithms are still a novelty. The levels outlined here are provisional and will be revised as new experimental observations are made.

Specialized Algorithms

If you want to show that computation is a good model, then the way to go about it is to show how the things that people do can be described by recipes or programs that make use of the brain ' s neurons in a feasible way. The brain ' s algorithms must be exotically different from those used by silicon computers in part because the brain ' s architecture is so different from silicon.

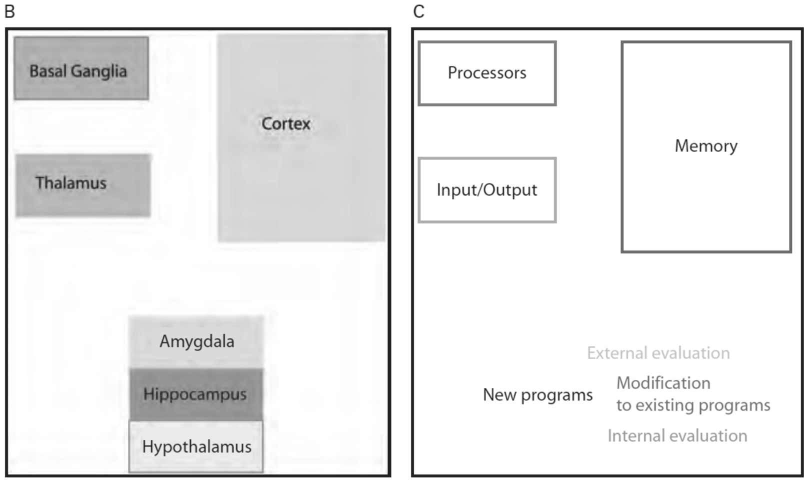

Figure: (B, C) Comparing silicon computer functions with those of the cortex. The brain has functions for acquiring new programs that make use of the components for storing and executing its current programs. The amygdala represents a potential program ' s importance from the standpoint of novelty, the hippocampus represents a sketch of the program in terms of existing programs, and the hypothalamus scores it with respect to existing programs.

Brain–computer interfaces (BCIs) are systems that translate a measure of a user's brain activity into messages or commands for an interactive application. A typical example of a BCI is a system that enables a user to move a ball on a computer screen toward the left or toward the right, by imagining left- or right-hand movement, respectively. The very term BCI was coined in the 1970s, and since then, interest and research efforts in BCIs have grown tremendously, with possibly hundreds of laboratories around the world studying this topic. This has resulted in a very large number of paradigms, methods, concepts, and applications of such technology.

In general, BCI systems can be categorized by brain signal pattern , stimulus modality, mode of operation, operation strategy, and recording method.

BCI systems

In 1889 Beck started studies on the electrical brain activity of animals. He recorded negative electrical potentials in several brain areas evoked by peripheral sensory impulses. Using this technique, Beck localised various centres in the brain of several animal species. In doing this, he discovered continuous electrical oscillations in the electrical brain activity and noted that these oscillations ceased after sensory stimulation. The oscillations which Beck and Cybulski saw in the fluctuating baseline led these authors to the idea of continuously recording the spontaneous electrical brain activity.[56]

Beck also found the spontaneous oscillations of brain potentials and showed that these fluctuations were not related to heart and breathing rhythms. Moreover, Beck mentioned the change in the potentials upon sensory stimulation. The evoked potentials were followed by a cessation of the fluctuations of the electrical waves as a consequence of afferent stimulation, either by electrical stimulation of the nervus ischiadicus or by peripheral stimulation with light flashes or handclaps.[57]

Beck claimed to be the discoverer of the electrical brain activity that is nowadays known as the electroencephalogram. Much later in 1924, the human brainwaves, in several frequency bands, were first measured by Hans Berger. In the early 1970s, Jacques Vidal took the first tentative step toward a BCI system.

The recent focus is on developing technology to interface the brain directly with music, games, mechanical prosthetics, or communication systems, a field of research generally known as Brain-Computer Interfacing (BCI).

BCI can be understand as a system that allows for the control of a machine by thinking about the task in question; e.g. controlling a robotic arm by thinking explicitly about moving an arm.[58] In this research project the model of a complex system is enhanced with artificial intelligence so that it can perform it's own interpretations of the meanings of EEG patterns, and this way is established the type of human-computer interaction or more precisely brain-computer interaction for this work.

We can identify three categories of BCI systems:

1. User oriented BCI system
2. Computer oriented BCI system
3. Mutually oriented BCI system

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56 Coenen, Anton, and Oksana Zayachkivska. "Adolf Beck: A Pioneer in Electroencephalography in between Richard Caton and Hans Berger." Advances in Cognitive Psychology 9, no. 4 (December 31, 2013): 216–21. https://doi.org/10.5709/acp-0148-3

57 Coenen, Anton, and Oksana Zayachkivska. "Adolf Beck: A Pioneer in Electroencephalography in between Richard Caton and Hans Berger." Advances in Cognitive Psychology 9, no. 4 (December 31, 2013): 216–21. https://doi.org/10.5709/acp-0148-3

58 Miranda, Eduardo R., and John Matthias. "Music Neurotechnology for Sound Synthesis: Sound Synthesis with Spiking Neuronal Networks." Leonardo 42, no. 5 (2009): 439-42. http://www.jstor.org/stable/40540063.

Proposed architectural BCI approach is mutually oriented BCI system, as the user and computer, or intelligent algorithm, mutually adapt to each other and build correlative environment.

Electroencephalography (EEG)

Neural activity generates electric fields that can be recorded with electrodes attached to the scalp. The electroencephalogram, or EEG, is the visual plotting of this signal. In current usage, the initials commonly refer to both the method of measurement and the electric fields themselves. These electric fields are with amplitudes in the order of only a few microvolts.[59] [60]

The EEG is measured as the voltage difference between two or more electrodes on the surface of the scalp, one of which is taken as a reference. There are basically two conventions for positioning the electrodes on the scalp: the 10-20Electrode Placement System (as recommended by the International Federation of Societies for EEG and Clinical Neurophysiology) and the Geodesic Sensor Net (developed by a firm called Electric Geodesies.[61]

The EEG expresses the overall activity of millions of neurons in the brain in terms of charge movement, but the electrodes can detect this only in the most superficial regions of the cerebral cortex. There are a number of approaches to quantitative EEG analysis, such as power spectrum, spectral centroid, Hjorth, event related potential (ERP) and correlation. [62]

Advanced Music Technology and Composition

In order to understand the emergence of music, it might be sufficient to assume only one set of evolutionary pressures: the need to communicate verbally.[63]

Effect of sound on a spatial perception

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59 E. Niedermeyer and F.H. Lopes da Silva, eds., Electroencephalography, 2nd Ed. (Munich, Germany: Urban and Schwartzenberg, 1987)

60 K.E. Misulis, Essentials of Clinical Neurophysiology (Boston, MA: Butterworth-Heinemann, 1997).

61 Electrical Geodesies, Inc. <http://www.egi.com/>. Accessed 21 June 2004.

62 Miranda, Eduardo R., and John Matthias. “Music Neurotechnology for Sound Synthesis: Sound Synthesis with Spiking Neuronal Networks.” Leonardo 42, no. 5 (2009): 439-42. http://www.jstor.org/stable/40540063.

63 Peretz, Isabelle, and Robert J. Zatorre. *The cognitive neuroscience of music*. Chapter 16, Neural specializations for tonal processing page 231,Robert J. Zatorre Oxford New York: Oxford University Press, 2003.

Sound perception and cognition can be conceptualised as a process, in which the firs stages are the least and the latest stages the most dependent on the attentional efforts of the listener.[64] [65] [66]

Music has proven to be one of the most important shaping forces in computer science.

Music can be viewed from three very powerful and complementary perspectives. It can be considered from the digital signal-processing point of view—such as the very hard problems of sound separation (like taking the noise of a fallen Coke can out of a music recording). It can be viewed from the perspective of musical cognition—how we interpret the language of music, what constitutes appreciation, and where does emotion come from? Finally music can be treated as artistic expression and narrative—a story to be told and feelings to be aroused. All three are important in their own right and allow the musical domain to be the perfect intellectual landscape for moving gracefully between technology and expression, science and art, private and public.

Psychoacoustics

Auditory psychophysics, or psychoacoustics, is the psychological or behavioural study of hearing—behavioural in that the participant is required to make a response to the sounds that are presented. As the name suggests, the aim of psychoacoustic research is to determine the relation between the physical stimuli (sounds) and the sensations produced in the listener. That we measure the behavioural responses of listeners is essentially why psychoacoustics is regarded as a branch of psychology, although many of the problems addressed by psychoacousticians have little to do with the popular conception of psychology. As we have seen throughout the book, psychoacoustic techniques can be used to study very “low-level” or

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[64] Shiffrin, R. M. and W. Schneider (1977) Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. Psychol. Rev. 84, 127–90.

[65] Näätänen, R. (1992) Attention and Brain Function. Hillsdale: Lawrence Erlbaum Associates. 3. Näätänen, R. and I.Winkler (1999) The concept of auditory stimulus representation in cognitive neuroscience. Psychol. Bull. 125, 826–59.

[66] Tervaniemi, M. (1999) Pre-attentive processing of musical information in the human brain. J. New Music Res. 28, 237–45.

“physiological” processes, such as the mechanical processes underlying the separation of sounds in the cochlea.

Hearing research covers a wide range of scientific disciplines. Physical acoustics tells us about the characteristics of sounds and how they propagate and interact with objects. It tells us about sound waves reaching the ear from a given sound source: about the nature of the stimulus, in other words. Physical acoustics also helps us understand how sounds are modified by structures in the ear. The biological processes involved in hearing can be studied in many ways and at different levels of detail. At a low level, molecular biology tells us about the machinery of cells in the auditory system: the special molecules that cause the unique behaviour of these cells. For understanding the overall function of the auditory system, however, two disciplines dominate: psychophysics and physiology.

Advanced Architecture

Architecture is the main domain and focused area of application of research outcomes as well as projection of the methods from the above mentioned scientific fields. The goal is the bridge in-between these research fields and establish a novel methods for architectural design and thinking.

Educated as an architect, I have found that many valuable concepts of architecture feed directly into computer design, but so far very little in the reverse, aside from populating our environment with smarter devices, in or behind the scenes. Thinking of buildings as enormous electromechanical devices has so far yielded few inspired applications. Even the Starship Enterprises architectural behaviour is limited to sliding doors. Buildings of the future will be like the backplanes of computers: "smart ready" (a term coined by the AMP Corporation for their Smart House program). Smart ready is a combination of prewiring and ubiquitous connectors for (future) signal sharing among appliances. You can later add processing of one kind or another, for example, to make the acoustic ambience of four walls in your living room sound like Carnegie Hall. Most examples of "intelligent environments" 1 have seen are missing the ability to sense human presence. It is the problem of personal computers scaled up: the environment cannot see or sense you. Even the thermostat is reporting the temperature of the wall, not whether you feel hot or cold. Future rooms will know that you just sat down to eat, that you have gone to sleep, just stepped into the shower, took the dog for a walk. A phone would never ring. If you are not there, it won't ring because you are not there.[67]

Digital Architecture

From a historical perspective, the incubation period of a new medium can be quite long. It took many years for people to think of moving a movie camera, versus just letting the actors move in front of it. It took thirty-two years to think of adding sound.

Intelligent Environments

The stability and development of a human-made and human-inhabited environment is determined by the degree of investment in theoretical and economic "intelligence" and the emergence of intelligent environments enhanced with architectural intelligence.

The intelligent environments consist of adaptive conditioning determined by the population themselves in a growth-monitoring and or mechanism-activating adaptive logic system. The intelligent environments learn about its resident and generate an attentive situation - shape. The behaviour of the shape is purposeful, and intelligent. When we speak of intelligent environments we traditionally define man as the object and the environment as the surrounding. But we could also consider the surrounding as the object and man as the environment, or at least make them both object and environment to each other. The intelligent environment has a functional image of itself (soundscape) and has ability to map a behaviour of actual (population) occupant activity, and monitor and regulate the environmental conditions and mediate the activity patterns through generation and growth of functional spaces. The intelligent environment suggest to maximise or minimise the personal contact, minimise a massive noises or conduct frequencies, minimise distances, capsulate successful space, performs lighting and provide efficient and accommodating environment.

[67] Nicholas Negroponte and Marty Asher. 1995. Being Digital (1st. ed.). Random House Inc., USA.

Intelligent Environments are aware of and sensitive to multiple users in the same environment. These multiple users may coexist, may be interacting, may be cooperating, or may even be conflicting interests. Systems also have to be resilient enough to cope with users which will try to use the system in unexpected ways and with the richness and variability of human's behaviour on a daily basis.[68] The behaviour is produced by psychological and physiological energetic demands human has learned to depend upon. In Rosenbleuth, Weiner and Bigelow, historic paper: "Behaviour, Purpose and Teleology" their conception considered a thing and its environment in terms of their mutual relation. It defined behaviour of the inanimate and animate within one frame of reference. The term feedback was first defined, and purposeful behaviour was then separated into feedback or teleological and non feedback or non teleological behaviour. The purpose is given by the development of error correction procedures; when the concept of evolutionary tree is expanded with errors which escape correction and alter the feedbacks, but pruned by death of those patterns which cannot survive when re-contexted by the evolving environment. Survival and purpose intermingle. Feedback, or purposeful behaviour, is in turn subdivided on predictive or non-predictive.[69],[70],[71]

Architectural Intelligence

Architectural Intelligence is a set of evolutionary mechanisms that has a capability to adapt the architectural organism to the new environmental situation or behavioural patterns of it's symbionts, in a sort-term or long-term interactions. The Architectural Intelligence is both adapting, changing and accommodating the environmental dynamic and behavioural conventions. The architectural intelligence is taught by its architect.

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[68] Augusto, Juan C, Vic Callaghan, Diane Cook, Achilles Kameas, and Ichiro Satoh. "'*Intelligent Environments: A Manifesto.*'" Human-Centric Computing and Information Sciences 3, no. 1 (June 15, 2013). https://doi.org/10.1186/2192-1962-3-12.

[69] Rosenblueth, A., Wiener, N., & Bigelow, J. (1943). *Behavior, purpose and teleology. Philosophy of Science, 10,* 18–24. https://doi.org/10.1086/286788

[70] Brodey, Warren. *The Design of Intelligent Environments: Soft Architecture*, Landscape (Autumn 1967)

[71] Brodey, Warren. *The Design of Intelligent Environments: Soft Architecture*, Landscape (Autumn 1967)

The intelligence is encoded in a script of a neural networks models that are capable of rewriting existing code protocols, and therefore actively address acute issues of architecture for effective and dynamic adaptability. My architectural approach proposes a theory of architectural adaptive systems. Intelligence can be seen as a form of adaptation in which knowledge is constructed by each individual through two complementary processes of assimilation and adaptation (Jean Piaget). Adaptation is an evolutionary process as a result of which the body better adapts to a dynamically changing environment. If an organism cannot move or change enough to maintain its long-term viability, it will obviously go extinct.

In this perspective, *Architectural Intelligence* is a set of methods that adapt architecture to the environmental and social changes and instability. Architectural intelligence is a method of solving architectural problems. We propose the use of computer science techniques, in particular deep learning and meta-learning, to represent and analyse complex architectural and urban phenomena and to find and generate optimal spatial forms. Modelling complex natural processes requires computer science and it is no coincidence that the development of computer science has been largely shaped by the construction of computer models to simulate natural processes. Based on the developed models, we generate intelligent architectural structures that provide sustainable environmental conditions for individuals and communities based on their spatial experience and behaviour. Predictions generated from models with the use of neural networks actively solve difficult problems of architecture in order to effectively adapt to dynamic changes in the environment.[72]

The position that computer-aided architecture is an issue of machine intelligence is an uncomfortable one. While I sincerely believe that the case is strong, the paradoxes and setbacks are over whelming to the point of making this position quite self-defeating for the researcher. Nevertheless, the fruits of continuing and the consequences of capitulating are so great that one can easily find incentives to try earnestly to understand the makings of intelligence and the makings of architecture. Without this understanding, I believe, the future of architecture, as aided, augmented, or replicated by computers, will be very gloomy in the technical hands of one-track-minded autocrats.

There is no doubt that computers can help in the humdrum activities of making architecture tick: smooth circulation, sound structures, viable financing. But I am not interested in that—I am interested in the rather singular goal of making the built environment responsive to me and to you, individually, a right I consider as important as the right to good education.

Nicolas Negroponte Soft Architecture machines, 1976

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[72] Kotnour K., and Lisek R. Evolving Architectures - Spatial Adaptation in Multidimensional Complex Dynamic Environment, 2020

The architecture it self will be computational machine the engine and the material powerful energy producer and transmitter so the demand on space will be significantly reduced.

There will be a several different architectural typologies for different form of computation. That computer architecture will be ever-present in a matter surrounding and creating our environment.

The computing capacity will be given by the material structuraslization and effectiveness of energy and data transmission.

1.7 Methodology

This research proposes a framework for advanced architectural design and thinking, based on modulation of the dynamic medium, classification of an extensive multidimensional data base, translated with architectural language into a compact and coherent intelligent environment in code.

Contextual Purposes

This work is based on two approaches, firstly on experimental work with multidimensional data collections, in the scope of this research, database of recoded brain responses on various audio stimuli and spectro-spatio-temporal experiences and features. Secondly on the form finding by logical and generative models, machine learning evolutionary algorithms, and generative neural networks. All resulting in Self-Controlled and Self-Replicable Computational Models and Algorithms for Advanced Architecture Design. The experimental work and coding is based on Python language along with TensorFlow and Keras libraries, with extension to advanced computer music audio-visual programming softwares (Processing, Pure Data, SuperCollider). The prototype of generative dynamic environments is developed and tested in various game engines (Unreal Engine, Processing, etc.) and exposed to multidimensional data - generated ambisonic sound signals. While there is continually compared: aural situation (in the sense of dynamic environment), evoked responses (perception), evolution of form (structure definition) data preprocessing (material), patterns recognition from recorded data bases, and defining the data representation and evolution of the form. The observations are described in detail for each case study of dynamic soundscape environment.

Motivation

The purpose of this work is deepen and investigate the knowledge we have up today in field of advanced computer music techniques on their mathematical background along with the technologies and possibilities of computational architecture. The goal of the thesis is establishing an autonomous model for Architecture revived with the Sound Synthesis, where particles, atoms in numbers meets waves, and quantum phonons, reveal in quantum systems of coherent structures and forms, fluid compositions of qubits. The the dynamic force in this model is dynamic force and energy of the sound. The thesis theoretical framework re-evaluate and re-define all complexities between a two domains, architecture and sound art, in the philosophical context to the foundations of quadrivium (astronomy, geometry, arithmetic, music) correlated with the corresponding scheme of coding (head, body, expression, evaluation).

Impact

The outlined frameworks and models should introduce a novel computational architecture methods and strategies of architectural creative process and architectural thinking. Research outcomes will provide a number of frameworks and case studies that deal with complex dynamic environments from soundscapes, up to quantum level evolutionary architectures. It should strengthen the digital literacy and outline the possibilities in a domain such an architecture which supervise it self, challenge and questions on the edge of technical and artistic design methods. The research of advanced computer music and architecture defines link between these two domains where on the side of architecture is a number in space and on side of music is a number in time and with powerful machine learning models and algorithms we classify these numbers, reveal patterns and structure them into the coded evolutionary architectures like a living autonomous and intelligent organism.

1.8 Discussion

The Intelligent Advanced Architectures, Generative Computer Aided Architecture, Advanced Computer Sound Synthesis, Natural Computing or Machine Learning are very progressive research fields, that this thesis adjust and refer to the results of recently published research and projects in these domains. Artificial Intelligence Architecture (AI-A) should react not only to the dynamic environment and balance the available energy resources and infrastructure, but it should also consider the absorption, accumulation and energy distribution within the architectural body. The architecture that harvest energies and allow a balanced symbiosis of artificial, human and natural environment. Listed experimental projects explores trough the spatial sound, the possibility to expand our mental capsule into the physical world, shared environment, and allow it to be interconnected with the built reality that surrounds us.

Human tends to constantly transform the environment, everyone who moves through the architectonic landscape immerse within, search for forgotten spaces. Those spaces that are constantly transformed, by the memory, saturated with meetings and creation, from which we can draw fragments and patterns of randomness and the ability to adapt.

The thesis emphasise a framework of Evolutionary Convolutional Neural Networks, form finding methods, spectral analysis, and other methods for pattern recognition. It provides a starting point for researchers at all levels of experience, but especially for novice researchers, in refining the conceptual clarity of their inquiry.

1.9 Research Contribution and Outcomes

What is the contribution comparing the recent design processes?

Neuro-Evolutionary Architecture technologies allow us to monitor our neural, physiological and psychological responses that are measurable from biofeedback influenced by natural, human and artificial human environments and our social and cultural behaviours. They help us understand what is the impact of the architectural environment on our neural activity and nervous systems. We are able to observe both our conscious and sub-conscious responses on initiation sound signals. In this way we are able to better understand how our brain and body respond to internal and external consequences and expand the architectural tree dimensional space into correlations of the multidimensional experience of reality. The way we experience our inhabited space is limited by our imaginative ability to transform a matrix, with a relationship of evolutionary interactions and the polarisation of internal and external forces that are mutating in forms, functions and structures, purpose. The building is understood as a dynamic organism that is driven by the creation of humans needs caused by the lack of instinctive adaptability.

This novel, authorial architectural approach, Architectural Intelligence, proposes a theory of architectural adaptive systems. Intelligence can be understood as a form of adaptation, while knowledge is based on two complementary processes of assimilation and adaptation[73]. Adaptation is an evolutionary process as a result of which the architectural body adapts better to a dynamically changing environment. If the organism cannot move or change enough to maintain long-term viability, it will obviously cause its extinction. In this perspective, Architectural Intelligence is a set of methods that adapt architecture to environmental and social change and instability. Architectural Intelligence is a method of solving architectural problems. I propose in particular the use of computer science techniques, deep learning and meta-learning, for the representation and analysis of complex architectural and spatial phenomena, for the search for and generation of optimal spatial forms.

Neuro-Evolutionary Architecture is an interaction between real, perceived, and imagined where actual leads into virtual and vice versa. It is an architecture that blends in and fills and dissolves these worlds in a form of impermanent narrative structures. The constantly presented true of limited three-dimensional illusion and continuous deceit is defaced.

In my work I outline new approaches to working with space, material and architecture of this space, sound-spatial structures are only one layer of the architecture of the future and the project Sound Shape Space is a case study of these new approaches, new architectures that work with current technologies and argue over technologies that we do not yet have available.

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[73] Piaget, Jean (1963). The origins of intelligence in children 2nd ed., New York: W.W. Norton & Company.

Research Outcomes

I developed Meta-Evolver, a tool for visual representation of dynamic environment models that correlate in a multilayer system (sound, neural activity, space). Meta-Evolver provides a virtual environment for testing dynamic spatial adaptation, where the environment consist of machine learning algorithms and parametrically defined geometry of space and integrates the ability to interact with the human user. This tool uses advanced methods of artificial intelligence (meta-learning) and cutting-edge technology, including innovative methods of architectural creation, immersive environments and virtual environments. The ability to constantly learn and adapt with limited experience in a dynamic environment is an important milestone on the way of creating interactive and immersive spaces in architecture with various forms of intelligence.

I. State of Art

Advanced Architecture

Algorithm Aided Architecture

Architectural Intelligence

- Digital Architectonic
- Architectural Language

Virtual Realities and Architectures

Advanced Computer Music

Granular Synthesis

Generated Music

- Musical Intelligence
- Intelligent Musical Machines

Ambisonics

Human Computer Interaction

Analogue Computers and UI

- First commercial Computers

Human Computer Interaction

- Brain Computer Interaction

Brain Sensing VR technology

Advanced Architecture

Architecture is the domain focused on application of research outcomes and of methods from the various scientific fields. The advanced architecture assumes the application of processes of information transmission in the environment and the fluent transfer of knowledge about the environment and behaviours of its inhabitants. The environment and behaviour are represented by functions and to estimate more precisely these complex functions advanced architecture must be approached with advanced computational and machine learning methods.

Algorithm Aided Architecture

Code writing represents a radical revolution for architectural design, made possible by the availability and development of computer and information technologies. Recent design methods, creative thinking and technical solutions are strongly influenced by the advent of algorithmization of processes and architectural designs. It has also changed the way we define architecture and its relationship with the outside world., and eventually the way we design and create space. The power of algebraic and geometric computerised algorithms allows us to design buildings in a completely different way from the past.[74]

In the 1935 Alan Turing was preoccupied whit a problem concerning probability. In one of his experiments he conceived of the idea of a universal computing machine. The idea was that the machine would be capable of performing any computable process by following a set of logical instructions on the tape. Later emerged the whole new science of Cybernetics and together with the Neuroscience outlined the first thought of an artificial intelligence that given the base for Cognitive science and Natural Computing. Since then, when applied first differential analyzer, a mechanical analog computer, and later when there was one room-sized computer for many people, or one computer for each, now when everyone owns several computing devices and personal wearables, we can build massive computational models of neural networks for the classification of large amounts of data targeted at certain communities, features and behavior. The artificial intelligent systems tailored for cities, architectures, groups on social networks, or individuals can be constructed. In Architecture the process relies on computational procedures that are very often pre-specified and preprogrammed in the infrastructure of the software. In

[74] Springer International Publishing AG 2018 M. Hemmerling and L. Cocchiarella (eds.), Informed Architecture, The Algorithms-Aided Design (AAD)

CAAD Computer Aided Architecture Design and Modelling the model of objects is determined by code writing. Coding is a new form of geometry.[75]

Later established The Architecture Machine Group - ARCH MAC, founded by Nicholas Negroponte and Leon Groisser in 1967, was a laboratory that tamed architecture, engineering, and computing in a new vision of architectural research and teaching. The group approached the architectural research with other fields and collaborations, their projects were intentionally multidisciplinary accentuated to the "promise of new methodologies for problem solving, especially those supported by memory and retrieval systems and manipulative possibilities of the computer." The concepts and demos of their research investigated with both the tangible and the representational techniques taught in computer science.

Figure: URBAN 5's overlay and the IBM 2250 model 1 cathode ray-tube used for URBAN 5 (source: openarchitectures.com)

Projects such as the URBAN 5 computing system, an early AI models for architectural design process, designed by Negroponte and Leon Groisser, resulted from the research on "Computer-Aided Urban Design" and their teaching in 1968. Later projects, such as the Spatial Data Management System (starting in 1978) and the Media Room spawned masters theses and dissertations, such as the Aspen Movie Map, a Proto-Google Map and Street View application that allowed its user to "drive" down streets in Aspen, Colorado, from an Eames chair equipped with joysticks in its armrests. These increasingly physical and spatial interfaces provided a locus for narrative in novel interfaces that blended the interests of architecture and engineering.

75 Bühlmann, V., Hovestadt, L., & Moosavi, V. (Eds.). (2015). Coding as literacy : Metalithikum iv. ProQuest Ebook Central

In 1985, Arch Mac folded into the MIT Media Lab. The choice of the term “media” referred to convergence, the increasing overlap of three industries: broadcast and motion pictures; print and publishing; and computers. With the change of scale, architecture had been absorbed into a broader notion of media and convergence, of research writ large, forging a vision for the experience of the digital.[76]

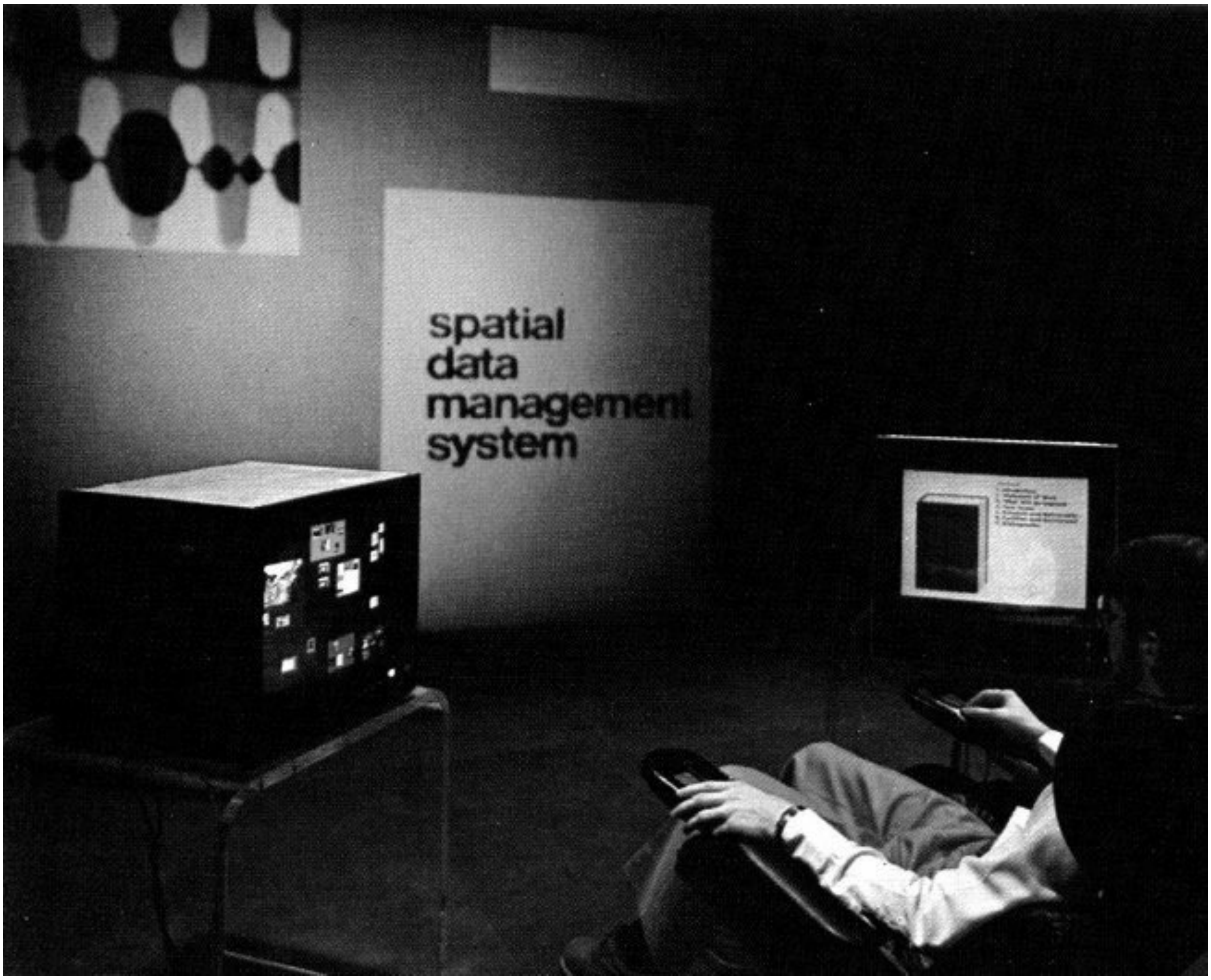


Figure: The Media Room of the MIT Spacial Data Management System, around 1977. The user sits in a comfortable armchair with an integrated joystick and touch-sensitive pad. Two monitors and a wall-size projection screen are used as displays.

Over the past fifty years, two digital revolutions—in computing and communication—have transformed our world. Neil Gershenfeld, Alan Gershenfeld, and Joel Cutcher-Gershenfeld FabLab MIT, foresee a third and even greater digital revolution in fabrication. The third digital revolution is about much more than 3D printers and hobbyist makers; it's about the convergence

76 https://radical-pedagogies.com/search-cases/a13-architecture-machine-group-media-lab-massachusetts-institute-technology-mit/

of the digital and physical worlds. The third digital revolution completes the first two revolutions by bringing the programability of the virtual world of bits into the physical world of atoms.[77] [78] The algoritmization of the supported processes, evolutionary strategies, adaptability range, applied to the programmed properties of the material bridges the edge between the digital and physical worlds. The understanding of the multi-layeredness and dimensions of reality will radically transforms forever.

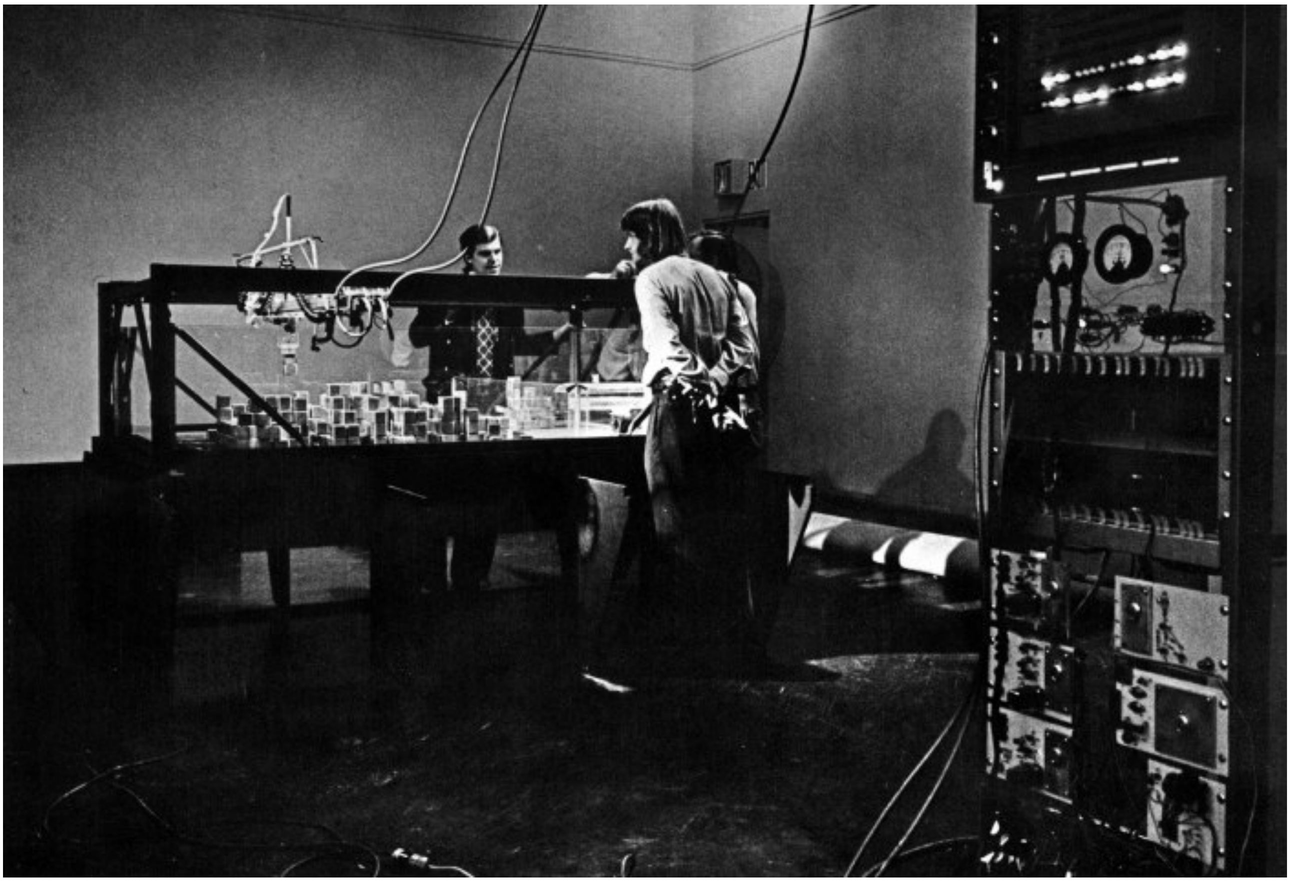


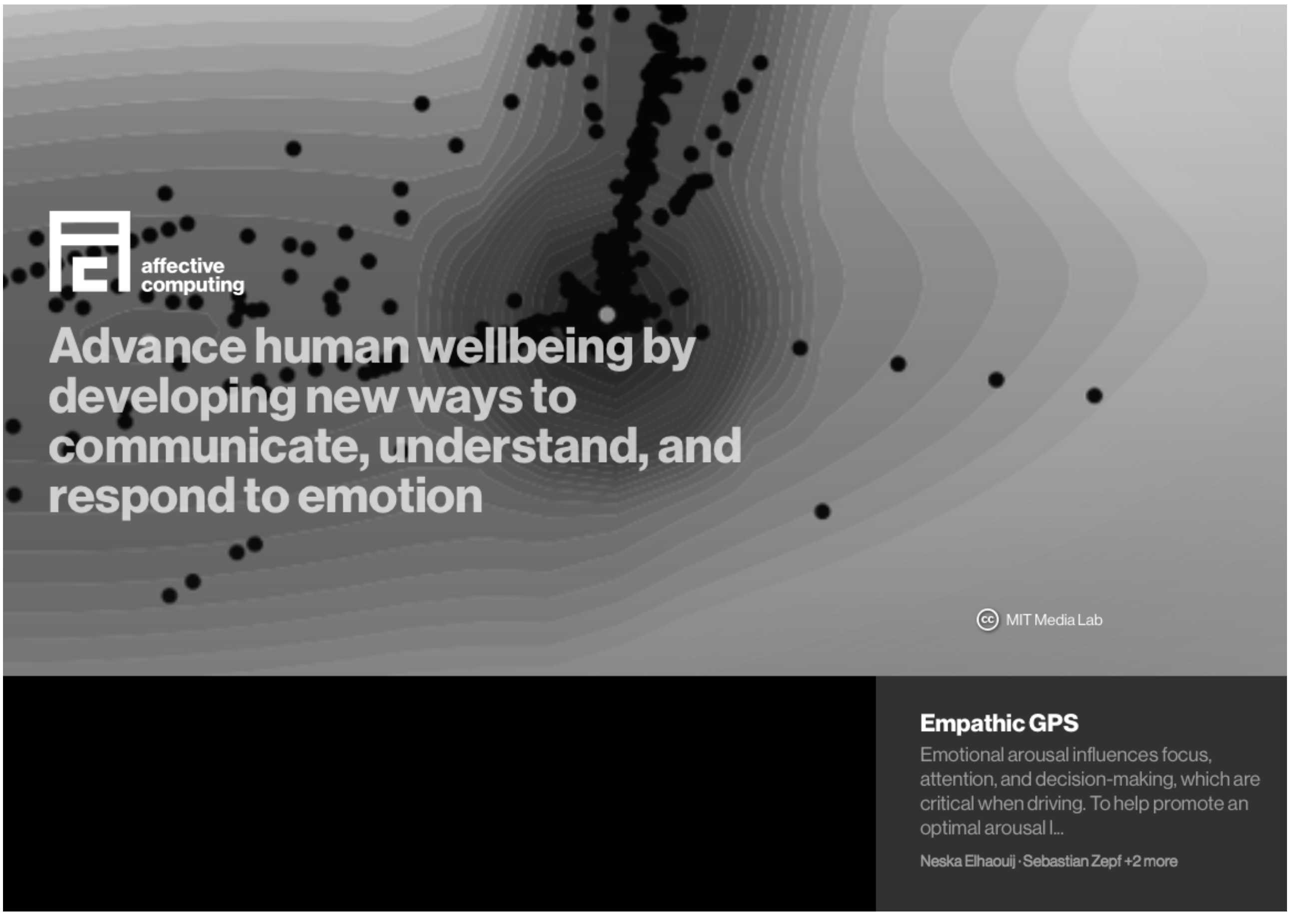
Figure: Seek' installation by Nicholas Negroponte and The Architecture Machine Group, 1970.

MIT's Center for Bits and Atoms is an interdisciplinary initiative exploring the boundary between computer science and physical science. CBA was launched by a National Science Foundation award in 2001 to create a unique digital fabrication facility that gathers tools across disciplines and length scales for making and measuring things. These include electron microscopes and

[77] http://designingreality.org

[78] Gershenfeld, Neil A., Alan Gershenfeld, and Joel Gershenfeld. Designing reality : how to survive and thrive in the third digital revolution. New York: Basic Books, 2017.

focused ion beam probes for nanostructures, laser micromachining and X-ray microtomography for microstructures, and multi-axis machining and 3D printing for macrostructures.[79]



Architectural Intelligence

The architectural language generate intelligent architectural structures that achieve balanced environmental conditions for individuals and communities based on their space experience and behaviour. The intelligence here is encoded in a script of algorithms and neural networks models that are capable of rewriting existing code protocols, and therefore actively address acute issues of architecture for effective and dynamic adaptability. They architect machine learning algorithms- the steps that a program will follow to complete a task. They put in place a set of starting conditions, after which the programs program themselves. The Architectural Intelligence is both adapting, changing and accommodating the environmental dynamic and behavioural conventions. The architecture have gone in this direction, and the efforts of every culture towards civilization are reflected in the places, houses and cities we create. In addition to providing us

79 http://cba.mit.edu/about/index.html

with protection, these structures also have a symbolic meaning, and are a continuity based on the lives of those who inhabit these places and environments.

The ubiquitous computing isn't a new observation a concept of it Mark Weiser introduced in 1991. "The most profound technologies are those that disappear," Weiser wrote: "They weave themselves into the fabric of everyday life until they are distinguishable from it." (Weiser, 2011) That's the world that Schmidt's describes: a world of sensors and intelligence that becomes the material of our daily lives. It becomes our architecture. Architecting is when we build a structure and relate detail to it. And when we talk about the role of humans in those systems, we call it architecture. As the conventionally trained architects who make unconventional approaches to architecture in our design of complex systems. Whether we would say it or not, under this definition, we architect. Architecting permit an exploration of the mechanisms behind and within design, and expands the boundaries of practice. It provides the means to model the implications of computation, generativity, and intelligence.

The architecture is ahead of different technological paradigms, such as cybernetics and artificial intelligence, that architects explored at the scale of buildings and the built environment. Molly Wight Steenson[80] raises further questions like how do architecting and architecture work when AI is part of the world around us, when algorithms determine so many aspects of our daily lives.

Evolutionary Architecture

An Evolutionary Architecture investigates fundamental form-generating processes in architecture, paralleling a wider scientific search for a theory of morphogenesis in the natural world. It proposes the model of nature as at the generating force for architectural form. The profligate prototyping and awesome creative power of natural evolution are emulated by creating virtual architectural models which respond to changing and dynamic environments. Successful developments are encouraged and evolved. Architecture is considered as a form of artificial life, subject, like the natural world, to principles of morphogenesis, genetic coding, replication and selection. The aim of evolutionary architecture is to achieve in the build environment the symbiotic behaviour and metabolic balance that are characteristic to the natural environment.

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80 Steenson, Molly W. Architectural intelligence : how designers and architects created the digital landscape. Cambridge, Massachusetts: The MIT Press, 2017.

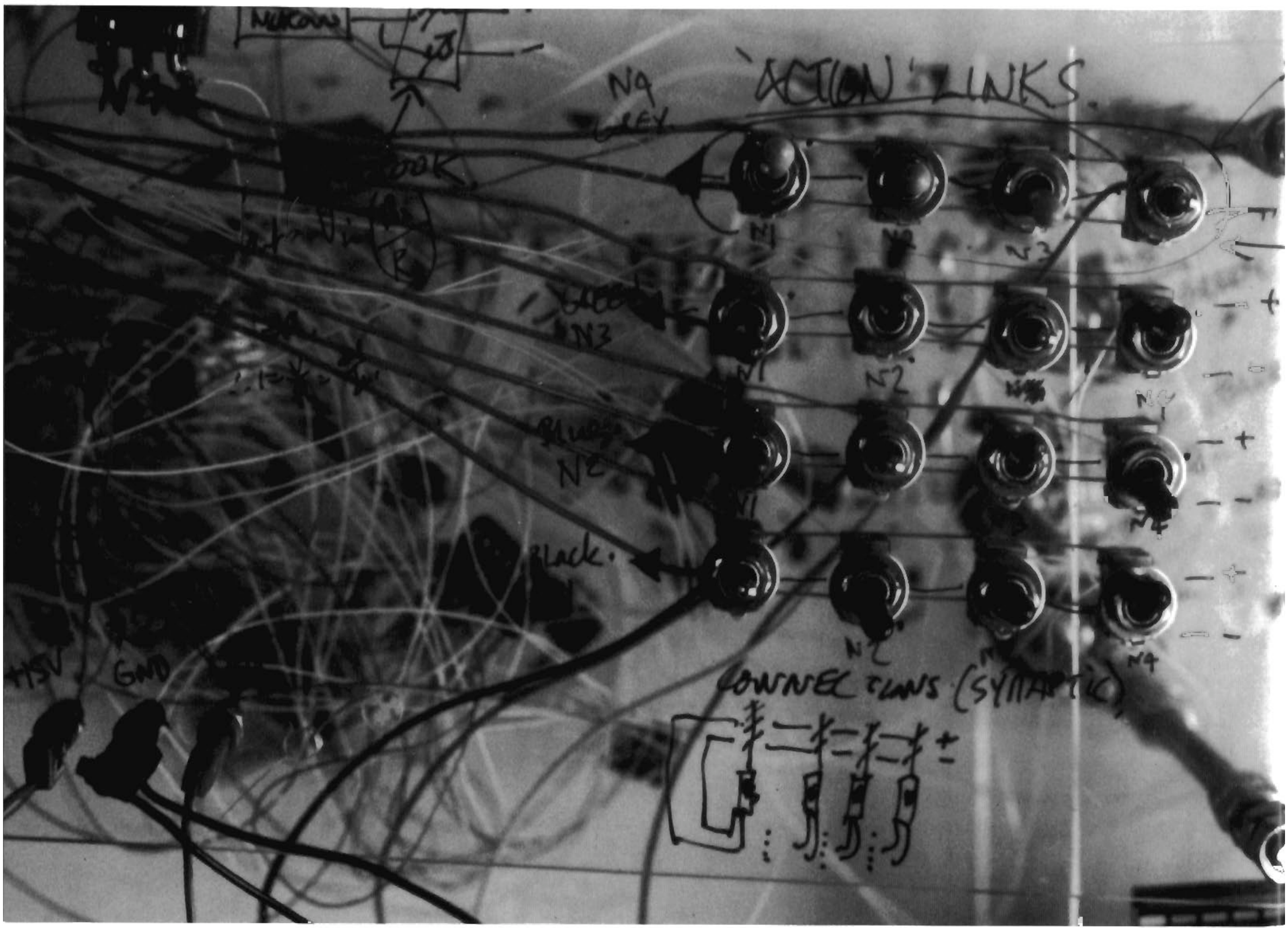

Figure: Analogue synthesiser

Artificial Life

John von Neumann managed to render extremely complicated things crystal clear. Toward this end, after addressing the logical foundations of mathematics, and the mathematical foundations of quantum mechanics, he finally focused on the mathematical- logical-biological foundations of computer science. He fathered the first computational approach to the generation of lifelike behavior. He tackled the definitions of logical universality, construction universality, and evolvability in computing machines and automata.[81]

In nature it is only the genetically coded information of form which evolves, but selection is based on the expression of this coded information in the outward form of an organism. The codes are manufacturing instructions, but their precise expression is environmentally dependent. This architectural model, considered as a form of artificial life, also contains coded manufacturing

[81] Marchal, Pierre. 1998. "John von Neumann: The Founding Father of Artificial Life." Artificial Life 4 (3): 229–35. https://doi.org/10.1162/106454698568567.

instructions which are environmentally dependent, but as in the real world model it is only the code script which evolves, but affects the emergence of forms as adaptable representation of optimal architectural system (building element, shelter, cluster of objects, settlements, cities, infrastructure). The coding of all natural forms in DNA is achieved with just four nucleotides, which in turn use just twenty triplets to specify the amino acids that manufacture protein. The hierarchical structure of living systems is analysed by James Miller on seven levels: cell, organ, organism, group, organisation, society and supranational system. Life emerge on the edge of chaos, and on this edge come forth Architectural Intelligence.

Digital Architectonics

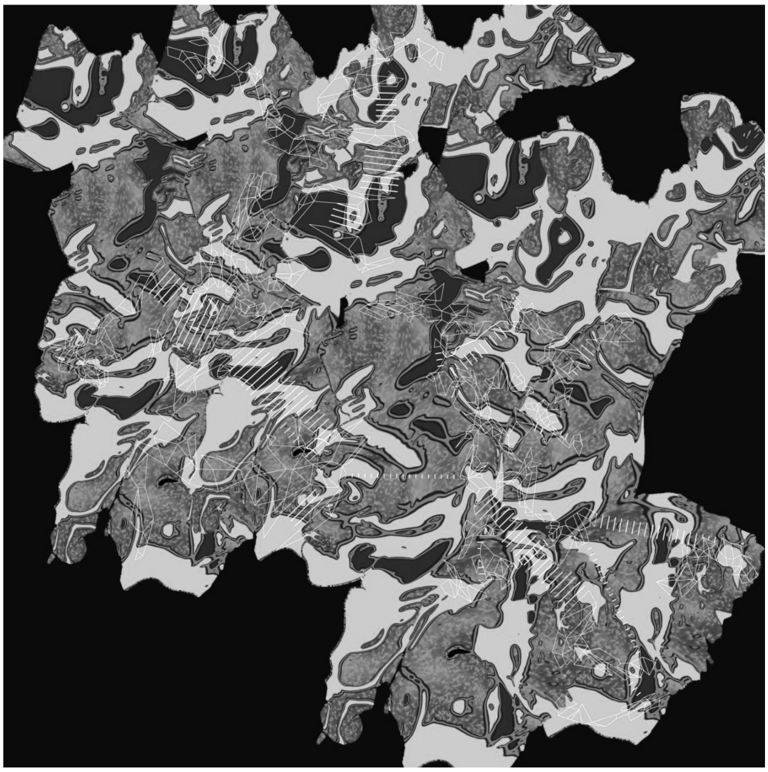

Figure: Studio Metheora, ETH Zurich, Digital Architectonics research group

Coding is a new form of geometry.[82]

Advanced Machine Learning and AI methods

[82] Bühlmann, V., Hovestadt, L., & Moosavi, V. (Eds.). (2015). Coding as literacy : Metalithikum iv. ProQuest Ebook Central

The main idea of machine learning is instead of explicitly telling the computer what to do we show the computer lots of examples of inputs and outputs and have the computer to learn the relationship between inputs and outputs automatically. The popular definition of machine learning or ML, as Tom Michell present it is as follows:

A computer program is said to learn form experience E with respect to some class of tasks T, and performance measure P, if its performance at tasks in T, as measured by P, improves with experience E.

Thus there are many different kinds of machine learning, depending on the nature of the task T we wish the system to learn, the nature of the performance measure P we use to evaluate the system, and the nature of the training signal or experience E we give it.

Shane Barrow and Gabriel Esquivel are aware that we are in a moment where architecture is redefining its position, moving from a subject-centered and systematic discourse to an object-oriented situation. Objects need not be natural, simple, or indestructible. Instead, objects will be defined only by their autonomous reality. They must be autonomous in two separate directions: emerging as something over and above their pieces, while also partly withholding themselves from relations with other entities.[83] Object-oriented ontology (OOO) is a metaphysical movement that rejects the privileging of human existence over that of nonhuman objects.[84] Specifically, object-oriented ontology opposes the anthropocentrism of Immanuel Kant's Copernican Revolution, whereby objects are said to conform to the mind of the subject and, in turn, become products of human cognition.[85]

Harman's object-oriented ontology opens up a unique possibility for rethinking the peculiar problems associated with the problem of nature. A return to the object would have to be understood as a turning away from a mythological or sentimental understanding of nature toward the particularities and the essential strangeness of the objects themselves. In this particular project, the use of a seashell, an object of nature, was a deliberate selection. By submitting this

83 Ruy, David. (2012). Returning to Strange Objects. Tarp Architecture Manual (Spring): p. 38 (2012)

84 Harman, Graham (2002). Tool-Being: Heidegger and the Metaphysics of Objects. Peru, Illinois: Open Court. p. 2. ISBN [[Special:BookSources/08126094449I08126094449 [[Category:Articles with invalid ISBNs]]]].

85 Bryant, Levi. "Onticology–A Manifesto for Object-Oriented Ontology, Part 1." Larval Subjects. Retrieved 9 September 2011.

"natural object" through a series of drawing translations, a new object related to its autonomous drawing process rather than nature was created. This object doesn't operate in normative representation.[86] [87]

Alisha Andrasek Cloud Osaka

Cloud Osaka exemplifies high-resolution open synthesis applied to a largescale urban master plan. Transportation hubs and highly urban train stations in particular, are becoming destinations in their own right: strong urban attractors, often showcasing some of the latest technologies.

Envisioned as a high-resolution urban interchange, Cloud Osaka embodies Biothing's approach to complex design synthesis across multiple orders of scale. Due to its central position in the city, a high convergence of users and one of Asia's densest transportation nodes found in the adjacent JR Osaka Station, the key driver for the project was to understand 2.5 million people traversing the site every day. This is nearly 10 times the number of daily passengers at the busiest airports in the world. Such an extreme volume of pedestrian traffic, compounded by other forms of traffic in the area, warranted choosing computational physics simulation ordinarily used to simulate systems like river flows; indeed, a key driver for the project became the concept of a "river of people".

Fluid dynamics applied with creative and unnatural values of "designer physics", was used to generate a highly porous and connective voxel cloud, absorbing large amounts of data from different scale systems. A bespoke computational toolset developed for this project is structured through few distinct computational layers. Data from the large voxel cloud generated through fluid dynamics is a base data layer, into which other systems feed. Custom software is written for the universal growth of lattice structures.

Simulation results suggested a landscape of elongated dune-like formations. Unnatural geography is crystallised from the city's specific pressures inflected on the interwoven flows of fine resolution physics. The extreme volume of pedestrians on the site reverberates throughout the whole project, being a natural fit for the information-packed, high-resolution design fabric. It addresses complexity and offers robustness in the face of immanent change. Dune-like massing

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[86] http://theoremas-gabe00fab.blogspot.com

[87] Reverberation of an Object Shane Bearrow, Gabriel Esquivel,Texas A&M University Department of Architecture

volumes of voxelised formations are programmed to swell into more or less development. Their field distribution into distinctly defined volumetric zones allows for phasing of construction.

Specific inflections in the curvatures that define the formal characteristics of this urban massing, resonate an otherworldly beauty of Mars dunes (which served as visual inspiration). The formal envelope was modelled based on the simulation results from the gravity, friction and viscosity of the strange liquids that are unlike the ones found on Earth. This “alien” approach to the aesthetic of strange and unseen, recalls the Japanese culture of manga and anime which, after the nuclear cataclysm of Hiroshima and Nagasaki, introduced a particular topic of unnatural and nature versus artifice. In this project a particular kind of urban fabric was introduced, that hybridises strands of nature and artifice, culture and technology.

A high-resolution adaptive structure is proposed to address the necessary heterogeneity of such a complex site. Instantiated into different zones of the voxel cloud, the structure grows higher in density in the zones mapped for heavier pedestrian traffic. A larger density was necessary not only for stronger structural support in some areas, but also for distributed and multiplied capturing of vibrational kinetic energy, as well as various IoT sensors that support pedestrian transient programming (such as data collection for AR- and VR-based shopping).

This intricate structural cloud is enhanced by the AR designer cloud, transporting the visitor into an experience of ephemeral discovery: unseen unnatural weather, inspired by the phenomena of sakura blossoms, which for a brief moment becomes a new form of weather in the fabric of this Japanese city. A ubiquitous yet fleeting, beautiful, strange cloud attracting people to gather, share and celebrate.

Never before have designers had access to material resolution at the scale of dust, or algorithmic profiles of matter. Nor was artificial intelligence part of the creative and construction process, evolving at the accelerated pace of computational time. New scale of structures is revealed, microstructures capable of finer blending of material states, architectured through novel processes of physics simulation, bridging the gap between design and structural analytics. New way to design-search is via pattern recognition, assisted by machine learning. Micro-precision design engineered for the massive application scales, increasingly malleable, plastic and intricate, primed for super-performance and unseen aesthetics.

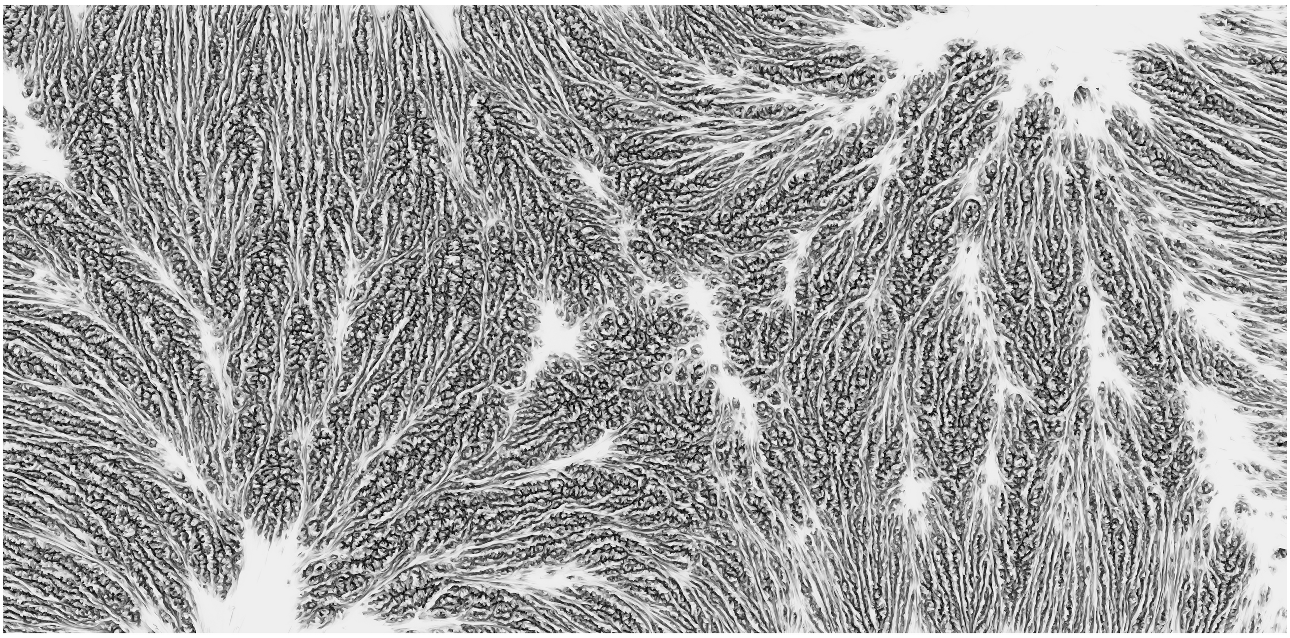

Figure: High Resolution Architecture: Microstructures by Alisha Andrasek

In her lecture at SCI Arc 2018 lecture in September 2018 https://www.youtube.com/watch?v=ddES1bV6U5I, https://www.alisaandrasek.com

Alisa Andrasek is an experimental practitioner and research based educator of architecture and computational processes in design. In 2001 she founded biothing, a cross-disciplinary laboratory that focuses on the generative potential of computational systems for design. In 2005 she initiated CONTINUUM, an interdisciplinary research collective focusing on advanced computational geometry and software development. Andrasek graduated from the University of Zagreb, and holds a Masters in Advanced Architectural Design from Columbia University.
http://www.lifestudy.ac.uk/bartlett/architecture/events/alisa-andrasek-lecture

UCL Bartlett School of Architecture [88]

https://www.sciarc.edu

Columbia University and the Van amen Institute - Brain Map of the City, New York's DUMBO neighbourhood [89] [90]

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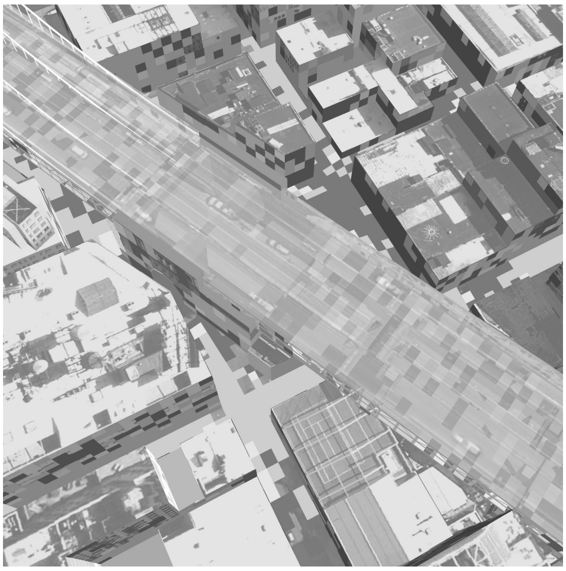
88 http://www.lifestudy.ac.uk/bartlett/architecture/events/alisa-andrasek-lecture

89 http://www.thecloudlab.org/dumbo_neural_cartography.html

90 https://www.vanalen.org/about/

A visualisation of mental phenomenon set within a neighbourhood of New York City. A group of volunteer citizen scientists contributed their brain waves in a collective visualisation of a day-in-a-life of a neighbourhood's mental states.



The project utilises the NeuroSky Mind Wave Mobile (a brain computer interface) and a custom app that tracks GPS and heading to associate what a person is experiencing with where they are perceiving. The map visualisation overlays many people's subjective experience to discover patterns and common responses to environmental stimuli such as parks, infrastructure and the block structure.

The DUMBO site is the third in a series of Neural Cartography projects by the Cloud Lab.

Digital architecture research centre [91]

Kent University School of Architecture [92]

Architectural Thinking [93]

Figure: Refik Anadol, Melting Memories: Engram as data sculpture - ZKM Karlsruhe [94]

91 https://research.kent.ac.uk/digital-architecture/

92 https://www.kent.ac.uk/courses/postgraduate/2720/bio-digital-architecture

93 https://www.sciarc.edu

94 https://vimeo.com/334752633

Anadol's work gathers data on the neural mechanisms of cognitive control from an EEG (electroencephalogram) that measures changes in brain wave activity. These data sets constitute the building blocks for the algorithms he works with. Melting Memories offered new insights into the representational possibilities emerging from the intersection of advanced technology and contemporary art. By showcasing several interdisciplinary projects that translate the elusive process of memory retrieval into data collections, the exhibition immersed visitors in Anadol’s creative vision of “recollection.”

“Science states meanings; art expresses them,” writes American philosopher John Dewey and draws a curious distinction between what he sees as the principal modes of communication in both disciplines. Comprising data paintings, augmented data sculptures and light projections, the project as a whole debuts new advances in technology that enable visitors to experience aesthetic interpretations of motor movements inside a human brain. Each work grows out of the artist’s impressive experiments with the advanced technology tools provided by the Neuroscape Laboratory at the University of California, San Francisco. Neuroscape is a neuroscience center focusing on technology creation and scientific research on brain function of both healthy and impaired individuals. Anadol gathers data on the neural mechanisms of cognitive control from an EEG (electroencephalogram) that measures changes in brain wave activity and provides

evidence of how the brain functions over time. These data sets constitute the building blocks for the unique algorithms that the artist needs for the multi-dimensional visual structures on display.

VVVV Workflow

Transposing EEG data in to procedural noise forms was a really engaging challenge, both technically and conceptually. In the input data and their mapped representation you can find recurrence and rhythm but also hints of higher dimensional structures. We wanted to do this efficiently and in real time and so working on Melting Memories dovetailed nicely with putting the last touches on FieldTrip, an (at the time pre-release) open source GPU library for HLSL/VVVV. It allowed us to use a composite design pattern to very quickly iterate while producing the aesthetic structures used in the project. This approach enabled us to really explore some deeper procedural functions whilst keeping a completely modular graphics pipeline. This modularity makes it easy and clean to expand on the project's abstracted content in really interesting ways, such as further integration of machine learning on the source data, evolving rendering techniques and the creation of sculpted physical artifacts.

Virtual Realities and Architectures

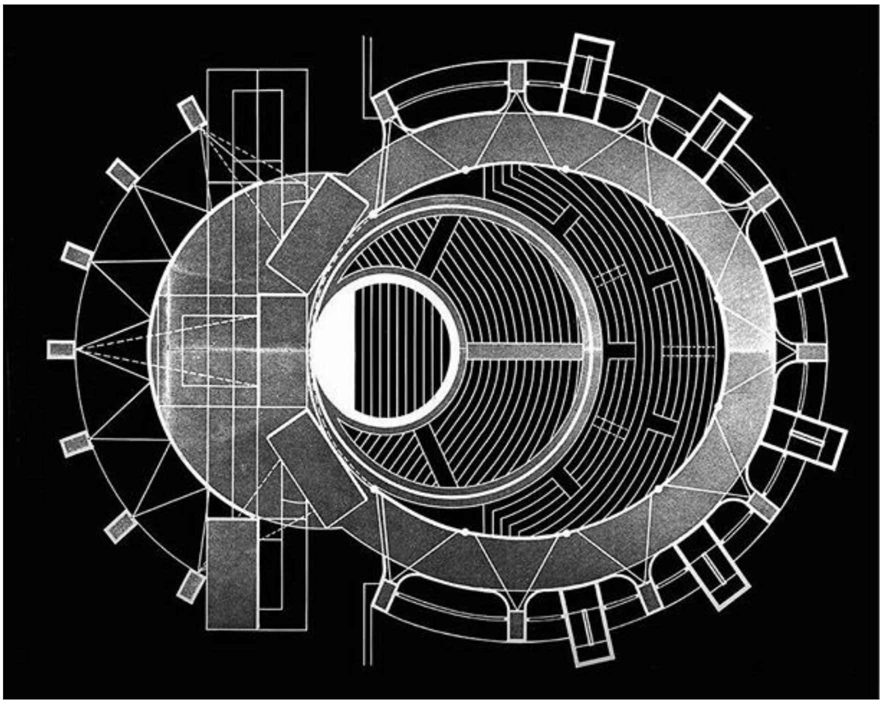


Figure: Total Theater: The Great Stage Machine Walter Gropius Richard Wagner concept for unified work of art in which all elements - music, voice, movement and spectacle - work together.

The computers, and new digital media, are opening the parallel multilayered spaces. The design and simulation capabilities of digital modelling take us to an unlimited imagination and understanding of space, and so redefine movement and communication. Virtual reality provides us an experience of vividly deep immersion and flow in spaces. In addition, today, and especially during the 2020 pandemic, more and more people are spending long hours or more in virtual worlds to "live" in cyberspace, where spatial experience, human-environment interactions and human-human interactions are very different from those in physical space. People can connect freely through hyper-links to other worlds and places, unlimited movement in space, parallel communication and the organization of cyberspace extends the current strict setting of physical space. This new space is between mental and physical space, because it provides designers not only with an unlimited imagination of mental space, but also with a perception of physical space in real life. This creates a new concept of humanity's space. (Liu et al. 2002; Wan et al. 2002). The initial dual concept of space in the history of architecture has been liberated. A new expanded concept of space is being developed thanks to digital design media. Now people can move back and forth in mental, physical and digital-virtual space as they wish. New media create new spaces; new spaces in turn create new architecture (Liu, 2003) and digital architecture.

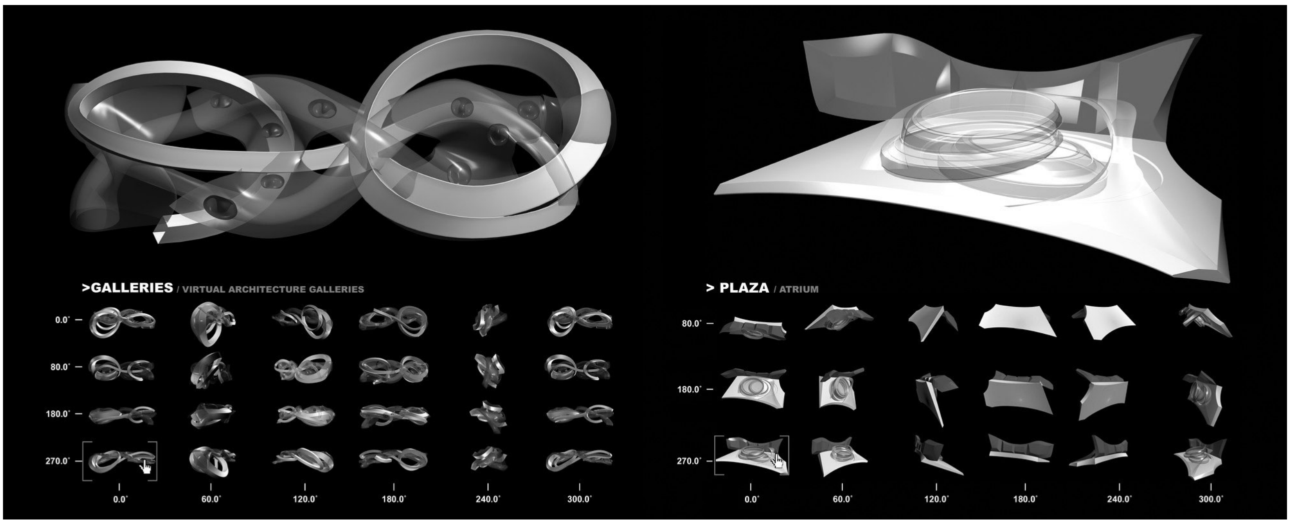


Figure: The source of critical approach to virtual spaces in architecture Barranh Helena, Between the Virtual and a Hard Place: The Dilemma of Digital Art Museums, 2016

Asymptote

Asymptote Architecture are spatial engineers of Guggenheim Virtual Museum.
As for the specific architectures we have to mention here also a digital galleries such as Google Art Project, DAM[95], and Artport[96]

Liquid Architecture by Marcos Novak[97]

Working in "non-traditional" architecture, his design thinking stems from exploring the spatial potential of new digital technologies, algorithmic compositions and music.

In particular, Novak analyses conformations, developing theories in respect of "hypersurfaces", a hybrid combination of "invisibility and virtuality".

His innovative professional career has led to him coining new terms such as "liquid architecture" and "transarchitecture", together with "navigable music", "habitable cinema", "archimusic" and several other terms which aptly illustrate his design methods.

These neologisms include the term "liquid architecture", coined in the publication Liquid architecture in cyberspace (1993).

Novak states that, in respect of architecture, the term "liquid" refers to an "animistic, animated, metamorphic entity, which crosses categorical boundaries and requires the cognitively supercharged operations of poetic thinking. Cyberspace is liquid. Liquid cyberspace, liquid architecture, liquid cities. Liquid architecture is more than kinetic architecture, robotic architecture, and architecture of fixed parts and variable links. Liquid architecture is an architecture that breathes and pulses. […] Liquid architecture makes liquid cities, cities that change with shifting values, where visitors from different backgrounds see different landmarks, where neighborhoods vary in line with common ideas and evolve as ideas mature or dissolve".

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95 http://www.dam.org

96 https://whitney.org/artport

97 https://www.floornature.com/marcos-novak-5052/

Figure: by Markos Novak, Mutable Algorithmic Landscapes, 2000

The term “transarchitecture” instead describes a transformation or transmutation of architecture intended to break down physical and virtual opposition, proposing a continuum ranging from physical architecture to architecture energized by technological augmentation to the architecture of cyberspace. Transarchitecture is offered as a way to expand and reinforce the scope and relevance of architecture in the computer age, and to allow alternatives to be considered beyond the narrow confines of construction disciplines. Transarchitecture examines aspects of technological and theoretical advances in space and their relation to the exploration of diverse spatial modalities which in the past were impossible to pursue. Computers should be seen as both tools to investigate these concepts of space and instigators of new architecture.” (Babele 2000, 2007).

For Novak, the very notion of architecture "is a hyper-extended concept where, alongside its core identity and function, construction of new structures goes beyond the physical limits of the same structure and form (T. De Feo). On the basis of this purely theoretical premise, Novak has designed numerous prototypes, workshops and actual installations, which are liquid architectures through mechanical measures, giving the impression of being somewhere between the physical and virtual domains (transarchitecture), albeit “used” through sensors.

The Brain Without the Body? Virtual Reality, Neuroscience and the Living Flesh by Par Marion Roussel[98]

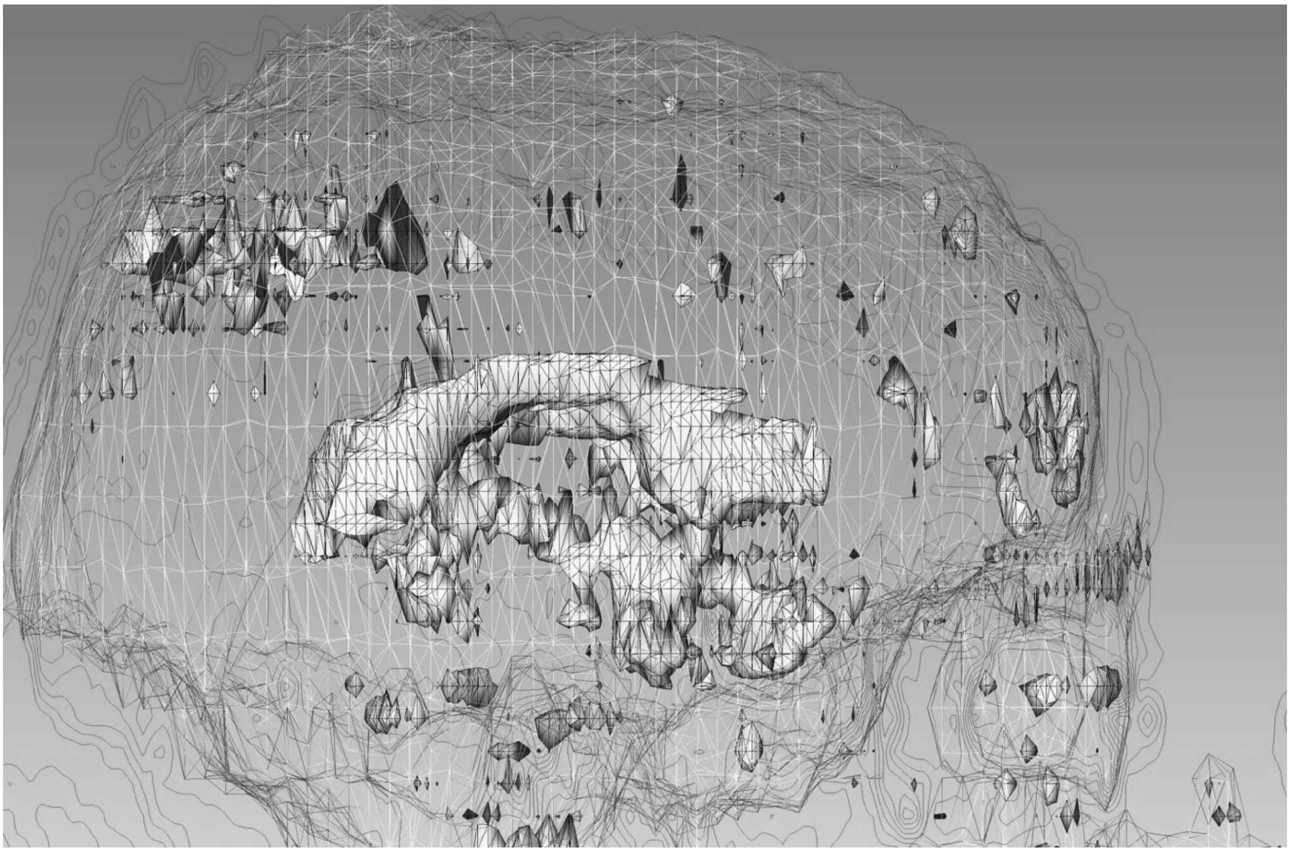

Figure: by Markos Novak, AlloBrain@AlloSphere, 2005

Since the early 1990s, the architect and artist Marcos Novak has been developing an experimental and transdisciplinary practice at a point of convergence between architecture, art, science, technology and philosophy, questioning the becoming of the digitally-enhanced body. With AlloBrain@AlloSphere, a virtual reality environment developed between 2005 and 2009 with the support of the Brain Mapping Center (University of California, Los Angeles), Novak proposes an immersive exploration of our brain spaces. AlloBrain is modelled from brain MRIs, extruded in the form of a three-dimensional volume. The experience offered is that of an immersion inside our heads. However, in this way of looking beyond the face, we find it hard to recognise ourselves. Projections or exteriorisations of a hidden interiority, the showing of these unknown territories of the body, of this anonymous and subterranean singularity, arouse an uncanny feeling in us. The explored interior is not that of the mind or of consciousness but, very strictly, that of the brain, more precisely that of a brain without a body, without flesh, a bare and digitally

98 https://angles.edel.univ-poitiers.fr/index.php?id=412

reconstructed enclosed space that yet appears empty of interiority. Are we dealing with a project that tries to explain the mind by mere brain matter, similar to the cognitive sciences or neurosciences? Still, the effect of uncanniness produced by the immersion in AlloBrain seems to result from the confrontation between this “naked brain” and our subjective experience, which seems unable to dispose of the physical body we inhabit and that inhabits us, too. Thus, what AlloBrain causes is a real return to the flesh, a lived-in and living flesh, highlighting a particularity that is nonetheless alien to us, because in reality something always resists. It not the thing that cannot be captured by digitisation the phenomenal “I” itself, the “I” by which we experience our body and the world? Such a hypothesis would give us ground to doubt that by avoiding the materiality of the body, by uploading our minds in the machine, we could remain the same.[99]
The AlloSphere. Source: Kuchera-Morin (2009)

Emanuel Dimas de Melo Pimenta

The Infinite of Architecture

“The projects developed by Pimenta are on the edge of architecture, neuroscience, cyberspace and virtual reality in Time, Space and Existence. Virtual does not mean exclusively what is immaterial, but rather what is potentially present. This is one of the meanings of the Latin word virtus, which also implies a sense of potentiality in the thing in itself. Generally, we say that something is "virtually" possible when we mean that it is potentially possible. But, beyond that, something that is virtual brings in itself the immanent presence of many possibilities, of the unexpected, of the surprise, of discovery.Infinite no longer in the sense of the far away without end, of the unreachable distant, but yes of what does not end in itself.
This is the essential meaning of virtus, of potentiality.
Today, you can easily reach images of the frontiers of the Universe, virtually walk on
Mars, or penetrate deeply into the atomic structure of matter using your small personal computer at home.
In this world, architecture design passed to can also be a scientific research, a work of art, a philosophical reflection, a book, a film, an installation - without ceasing to be architecture.
The role of identifying the various dimensions of the infinity became something characteristic of

[99] Roussel, M. (2016). The Brain Without the Body? Virtual Reality, Neuroscience and the Living Flesh. Angles, 2. https://doi.org/10.4000/angles.1872

each one of us, like poetry.

In such shared trans-dimensional creative work we become aware of the logical structure of thought.

Architecture is time design. When we change the space fabric, we also change who we are.

Design of thought.

Since the beginning, in the early 1980s, I have had these principles as essential to my work. In 1980 I coined the concept of "virtual architecture" - a method to work with synthetic and integral virtual systems on architecture. In that same year, I started the elaboration of the first virtual planet in history, anticipating Second Life in more than twenty years. In 2000 I started working on space architecture.

In the design of thought, what I call "logical traps" has always been present - subversive elements at a logical level that unchains awareness. Only difference produces consciousness. In this way, architecture is transformed into enlightenment, permanent discovery, self-knowledge.

Such an approach leads, since the first moments, to a permanent research on Theory of Thought, on neurology - specially space-time cognition, and also on cyberspace and on logic.

In a clear sequence after Richard Buckminster Fuller and Paolo Soleri among some others, it is a process that generates a new architecture, in dynamic symbiosis producing a new sense of human scale.

One could call this an "experimental architecture" - but, not only it is to be built, as all architecture ought always be experimental, it should always take life as a powerful laboratory to discover the human space-time of the future. Because the future is now: a present in permanent metamorphosis.

As Bucky Fuller said: don't fight forces, use them.

No longer the architecture-shell, the architecture as decoration or illustration, or art as urban handicraft. But yes an architecture-thought, creative, discovery, infinite in itself."

Emanuel Dimas de Melo Pimenta

Venezia, 2016

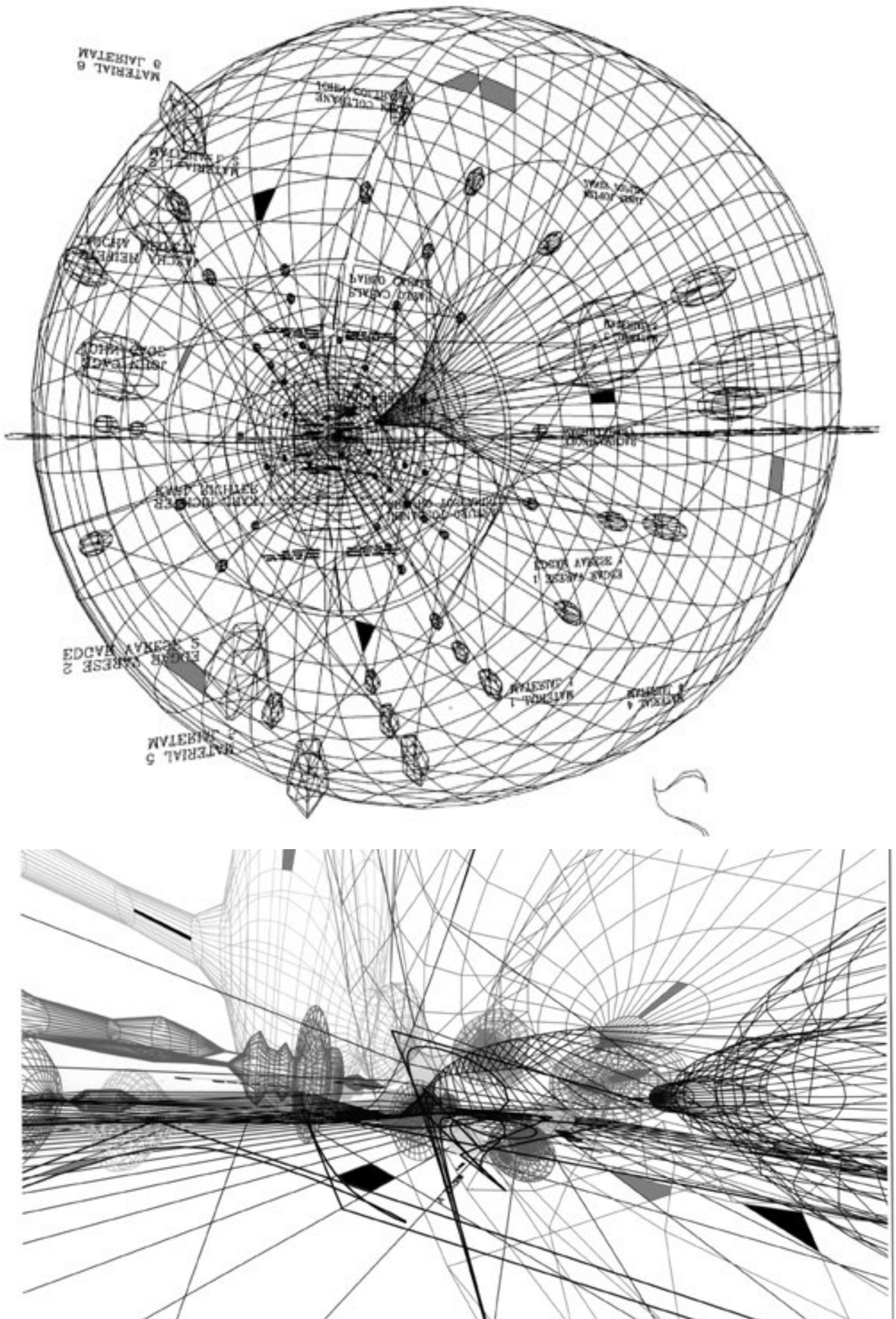

Figure: Through the Looking Glass 1993, Emanuel Dimas de Melo Pimenta

In the end of the 1970s, Emanuel Pimenta elaborated a new method for music composition and notation inside virtual environments. Starting from the two-dimensional graphical scores, also known as planimetrics, Pimenta expanded to four-dimensional systems. He studied with the German composer Hans Joachim Koellreutter - students of Paul Hindemith, Marcel Moyse, Kurt Thomas and Hermann Scherchen - among others. Pimenta recorded about four hundred compositions in electronic, digital, acoustic and electroacoustic music. Many people ask about listening to his music in this site - the problem is that Emanuel Pimenta works with a wide range of frequencies, and that compression systems like MP3 eliminate a good part of them.

Both on architecture and on music, Emanuel Pimenta works on the establishment of sensorial design - a term coined by him in the 1980s - and its implications in the plastic formation of synaptic patterns; it is what he calls logical traps.

Seeing the Unseen. Optic, Acoustic and the Space Between by Matheo Melioli

It is at this time that a whole world corresponds to the extreme transience of perceived space, one unveiled by the creative force of the invisible, by the power of absence and dream, where architectures far removed from the time and space of our perception reveal themselves to our senses due to the strength of their unconscious ties.

In his research explores the concept of space as it evolves in response to perception and phenomenology, cutting across the fields of architecture, music and the visual arts. Space comes to be understood as an interaction between the environment and the subject who experiences its phenomenal properties such as sound and light reflections. Therefore, space is in a dimension between the Euclidean world-objective and deterministic-and the sensorial space conditioned by the observer's physicality and by those mechanisms governing perception.

Ghost Spaces will demonstrate how sensorial stimuli are able to turn architecture into an elastic medium, altering and slowing down the recognition of the real space, prompting a sort of transfer in the perceived image.

Referring to Durant, Bachelard and Virilio, the profiles of this aesthetic experience undergo alteration, and the phenomenon itself is transferred into an analogue that progressively acquires the role of a substitute.

In this aesthetic-ecstatic shifting, space proceeds from an aggregate of permanent objects-connected by causal relations-to a new, almost virtual, condition where architectures are built up into a state of mobile and plastic images. In this scenario, as the causal constrictions falter, spaces appear as images always in flux, creating their dimensions without fixed boundaries.

Ghost Spaces is therefore an unpredictable and instable world, suspended between disappearance and reappearance, loss and resurfacing. This world corresponds to the fixity of the noumenal space, and another one revealed by the senses, by the creative power of the invisible, by the strength of absence and dream.

Advanced Computer Music

The theory of granular synthesis was initially proposed in conjunction with a theory of hearing by the physicist Dennis Gabor.[100] [101] Gabor referred to the grains as acoustical quanta, and he postulated that a granular or quantum representation could be used to describe any sound. This conjecture was verified mathematically by Bastiaans.[102] Others, including the mathematician Nobert Wiener and the information theorist Abraham Moles, also adopted a quantum view of musical sound. To Wiener[103], a quantum view of sound, which incorporates a temporal model, offered a more complete picture than that provided by the timeless Fourier analysis approach. Moles[104] segmented the space of audible sounds into small "quanta" for the purpose of measuring the information content of a sonic message. Iannis Xenakis, in his book Formalized Music[105], was the first to explicate a compositional theory for grains of sound. He described a

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100 Gabor, D. 1946. "Theory of Communication." Journal of the Institute of Electrical Engineers Part III, 93: 429-457.

101 Gabor, D. 1947. "Acoustical Quanta and the Theory of Hearing." Nature 159(1044):591-594

102 Bastiaans, M. 1980. "Gabor's Expansion of a Signal into Gaussian Elementary Signals." Proceedings of the IEEE 68:538-539

103 Wiener, N. 1964. "Spatial-temporal Continuity, Quantum Theory, and Music." In M. Capek, ed. 1975. The Concepts of Space and Time. Boston: Reidel,

104 Moles, A. 1968. Information Theory and Esthetic Perception. Urbana: University of Illinois Press.

105 Xenakis, I. 1971. Formalized Music. Bloomington: In- diana University

possible approximation to Gabor's model in the context of an analog synthesis implementation, and he suggested that the grain waveforms could be calculated directly by an appropriately programmed digital computer.[106]

Grain is a basic building block of larger sound objects that, when generated a mass, aids to the formations of complex sonic textures. Grains are represented within the frequency domain as the pitch of the waveform, and in the time domain as grain duration, start time or envelope shape.

Grain duration defines the size of individual sound particles. Alternatively, the term grain size may be used. Start time or phase indicates the position of the playhead within the grain.

Grain density is the amount of particles generated per second. The parameter sorts out the overall distribution of grains within the cloud, i.e. packed close together or spread apart. Density is interrelated with the grain duration as the more particles are generated, the more overlaps between them are happening. The denser the texture, the richer the timbral qualities of the sound, while sparse distribution of grains yields more rhythmic results. Inter-onset time sets the gap time between the grains, either for all as in synchronous engines, or through application of random modulation of the parameter in asynchronous ones. This parameter is also often called spray.

Pitch describes the frequency of individual grains, accomplished by playing them back at different sample rates, and in synchronous engines is tightly connected with the density parameter.

Grain shape is expressed through the various types of envelope functions applied to the amplitude of sound particles. Typical envelope shapes used are gaussian, quasi-gaussian, triangular, three-stage line segment, sinc function, expodec and rexpodec. Each of these envelope functions expectedly yields very different timbral and temporal results. Amplitude refers to a macro parameter responsible for the overall loudness of the texture.

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106 Roads, Curtis. “Introduction to Granular Synthesis.” Computer Music Journal 12, no. 2 (1988): 11. https://doi.org/10.2307/3679937.

Granular Synthesis[107]

Granular Synthesis is the most fundamental technique upon which all the other ones are derived from. Any sampled or periodic waveform will suffice as it is disassembled into microscopic sound particles ranging from 1ms to 100ms. Parametrization is expressed through the already familiar grain shape, grain duration, grain density, start time and pitch.

Glisson Synthesis is very similar to the basic granular synthesis technique, however the method requires an additional frequency path to be implemented within grains for glissando-like effects. This requires frequency start and frequency end parameters along with definable trajectory curvature settings.

Grainlet Synthesis is somewhat a hybrid of basic granular and wavelet synthesis types. Wavelets are essentially very short wave-like oscillations. Unlike with grains, the duration of a wavelet is inversely linked to its frequency. In grain let synthesis this inverse relationship is exploited on a broader scale by creating various linked combinations of synthesiser parameters, i.e. space/duration, frequency/space, frequency/duration, amplitude/space, etc. Train let Synthesis differs from the rest specifically by the content of the grain waveform, which in this case is a live-synthesised band-limited impulse train, rather than a sampled or periodic waveform. We define a trainlet by its attack time, pulse period (or frequency if at audio rate), harmonic structure (or spectra) and the relationship between high and low harmonic content, known as harmonic balance (or chroma). The rest of the parameters are identical to the previously described variations of particle synthesis.

Pulsar Synthesis is a technique aided by the concept commonly found in classic analog synthesis, namely a waveform's duty cycle, however in this case it is applicable to any arbitrary waveform, not just square waves,. Pulsar is formed by the combination of a pulsaret (a brief band-limited impulse signal) followed by a short segment of silence. The duration of the pulsaret is what makes up the duty cycle of the signal, while the duration of the pulsar itself is expressed as the pulsar period. A repeated series of pulsars creates a pulsar train

[107] https://www.perfectcircuit.com/signal/microsound

Formant Synthesis is a method of generating sounds that possess timbral qualities reminiscent of vocal vowels and some traditional music instruments. By technical definition, formant is a peak energy of the spectrum that contains both harmonic and inharmonic partials as well as noise.

Generated Music

First programmed music

Ferrati Mark 1

In November 1951 the Ferranti Mark 1Offsite Link performed Baa Baa Black Sheep and a truncated version of In the Mood at the University of Manchester. The program for Baa Baa Black Sheep was written by Christopher StracheyOffsite Link. Because the music played on the CSIRAC in Sydney, Australia a few months earlier was not recorded,h te recording on acetate disc of these brief performances for a small audience of technicians, may be the oldest known recordings of computer-generated music.

AI Experiments in Musical Intelligence

Experiments in Musical Intelligence, EMI is an analysis program that uses its output to compose new examples of music in the style of the music in its database without replicating any of those pieces exactly.[108] The program would analyze music Cope had entered enter into EMI's database, and that input would be used to direct the composition of new works in the same style. EMI doesn't generate style on its own. It depends on mimicking prior composers.[109]

Cope produced several more albums using EMI, including Virtual Mozart and Virtual Rachmaninov. EMI even composed a complete symphony in the style of Mozart which was performed at the Santa Cruz Baroque Festival in 1997. Cope has produced thousands of other works in various styles using EMI, including 5,000 Bach chorales available on his website. These pieces composed by Emmy challenged many notions, not only about musical style, but of how computers can be used within the arts as a whole. EMI produced music that could fool some of

108 Tech Closeup: Music Professor David Cope

109 https://computerhistory.org/blog/algorithmic-music-david-cope-and-emi/

the most knowledgeable classical music fans, but at the same time it relied on the input of existing works.[110]

Figure: Operating the Ferranti Mark 1Musical Intelligence / Image Source: ia.acs.org.au

Ambisonics

Ambisonics is a method for recording, mixing and playing back three-dimensional 360-degree audio. It was invented in the 1970s but was never commercially adopted until recently with the development of the VR industry which requires 360° audio solutions.

The basic approach of Ambisonics is to treat an audio scene as a full 360-degree sphere of sound coming from different directions around a center point. The center point is where the microphone is placed while recording, or where the listener's 'sweet spot' is located while playing back.

The most popular Ambisonics format today, widely used in VR and 360 video, is a 4-channel format called Ambisonics B-format, which uses as few as four channels (more on which below) to reproduce a complete sphere of sound.

110 https://computerhistory.org/blog/algorithmic-music-david-cope-and-emi/

Ambisonics 360 audio is sometimes confused with traditional surround sound technologies. But they are not the same, and there are major differences between them. And there are reasons why Ambisonics, rather than classic surround formats, has been adopted as the technology of choice for emerging VR and 360 applications.

Traditional surround technologies are more immersive than simple two-channel stereo, but the principle behind them is the same: they all create an audio image by sending audio to a specific, pre-determined array of speakers. Stereo sends audio to two speakers; 5.1 surround to six; 7.1 to eight; and so on.

By contrast, Ambisonics does not send audio signal to any particular number of speakers; it is "speaker-agnostic." Instead, Ambisonics can be decoded to any speaker array (more on which below). Ambisonic audio represents a full, uninterrupted sphere of sound, without being restricted by the limitations of any specific playback system.

Spherical harmonics

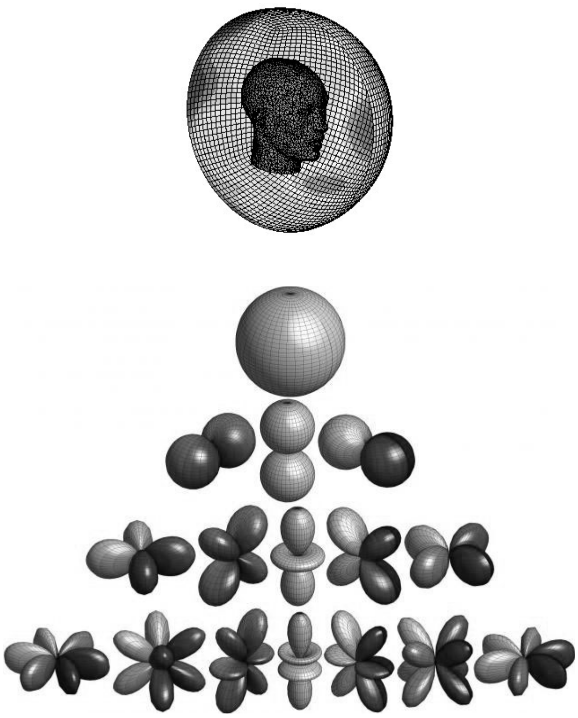

Figure: The spatial sound-field is projected unto "Spherical harmonics" the number of the order ambisonics and shape of the spherical harmonics

Higher-order ambisonics (HOA) provides a framework for representing a measured soundfield by its spherical harmonic expansion, in which each HOA signal represents a different term of the expansion. The maximum expansion order that can be computed from a given recording is limited by the number of microphones on the recording array. Since spherical microphone arrays can only provide a spatial sampling of the pressure on the sphere, rather than the pressure everywhere on the surface of the sphere, there will necessarily be errors in the analysis of the soundfield. Strategies to mitigate these errors as well as the perceptual consequences of such errors are currently being investigated.

One approach to generating a binaural rendering of a soundfield is by simulating playback over a real HOA loudspeaker array. Research has shown that listeners inside a real HOA loudspeaker array experience a realistic impression of the measured soundfield since the reconstructed sound waves are able to interact with the listener's morphology naturally. Therefore, a realistic binaural rendering of the soundfield can be obtained by filtering each loudspeaker signal by the corresponding head-related transfer function (HRTF) of the listener. T

Intelligent Musical Machines

Intelligent Musical Machines offers a way to make new kinds of music, sound and creative arts experiences using machine learning, machine listening and artificial intelligence.

MIMIC is a web platform for the artistic exploration of musical machine learning and machine listening. We have designed this collaborative platform as an interactive online coding environment, engineered to bring new technologies in AI and signal processing to artists, composers, musicians and performers all over the world. The MIMIC platform has a built-in audio engine, machine learning and machine listening tools that makes it easy for creative coders to get started using these techniques in their own artistic projects. The platform also includes various examples of how to integrate external machine learning systems for sound, music and art making. These examples can be forked and further developed by the users of the platform. Over the next three years, we aim to integrate brand new and developing creative systems into this platform so that they can be more easily used by musicians and artists in the creation of entirely new music, sound, and media, enabling people to understand and apply new computational techniques such as Machine Learning in their own creative work.[111]

MIMIC or "Musically Intelligent Machines Interacting Creatively" is a three year AHRC-funded project, run by teams at Goldsmiths College, Durham University and the University of Sussex.[112]

AI-terity, Artificial Intelligence (AI) musical instrument

AI-terity is a new musical instrument, built and developed by Koray Tahiroğlu, Miranda Kastemaa and Oskar Koli in SOPI research group, Aalto University School of ARTS. The instrument comprises computational features of an artificial intelligence (AI) method to generate audio samples for real-time audio synthesis. In this work, SOPI research group implemented a novel hybrid architecture, applying features of a Generative Adversarial Network (GAN) method to another GAN model. The hybrid method has the ability to specify particular audio features to be present or absent in the generated audio samples.

AI-terity requires the musician to physically manipulate the instrument, bend, twist and explore its soundworld. AI-terity musical instrument was presented at the Ars Electronica Festival 2020 and at the International Conference on New Interfaces for Musical Expression (NIME) 2020.

Sound and Physical Interaction (SOPI) research group's main interests are centred on the broad area of Sound and Music Computing (SMC) and New Interfaces for Musical Expression (NIME). In particular, the research in SOPI focuses on the emerging role of audio and music technologies in digital musical interactions. It includes building, implementation and performance of novel interfaces and instruments for music, interactive art and audio-visual production. The research builds on ideas from real-world physical interactions in digital environments, audio-tactile augmentation, embodied interaction, smart technologies and new interfaces for musical expression. SOPI research group is led by Koray Tahiroğlu and received funding from Academy of Finland, Nokia Research Center, TEKES, Aalto Tenure Committee and A!OLE Aalto Online Learning network .[113]

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111 https://mimicproject.com/about

112 http://strangeloop.co.uk/js-videos/video3.html

113 https://sopi.aalto.fi/blog/2021/08/09/ai-terity-2-0-an-autonomous-nime-featuring-ganspacesynth-deep-learning-model/

Human Computer Interaction

Analogue Computers and UI[114]

Vannevar Bush's differential analyzer

The first widely practical general purpose differential analyser was constructed by Harold Locke Hazen and Vannevar Bush at MIT, 1928–1931The differential analyser is a mechanical analogue computer designed to solve differential equations by integration, using wheel-and-disc mechanisms to perform the integration.[115]It was one of the first advanced computing devices to be used operationally.[116]

Bush's Differential Analyzer was big and complex. Six integrators and several input and output tables had to be carefully connected for each new problem. Doing so required both mechanical skill and a willingness to get covered in oil.

Moore School Differential Analyzer

The Moore School and U.S. Army's Aberdeen Proving Grounds used copies of Bush's Differential Analyzer to compute artillery tables. These were too slow, inspiring work on the faster ENIAC.

UCLA's Mechanical Brain: 1948

UCLA's Differential Analyzer, a mechanical computer, in 1948. "In December of 1977, the last working model of a mechanical differential analyzer in the world is donated by UCLA to the Smithsonian Institution for its pioneering computing display. The differential analyzer introduced much of Southern California industry to automatic computing, but became obsolete beginning in 1960 as it was replaced by computing machines with electronic circuits and vacuum tubes. From 1960 on, it was used mainly as a display piece, clanking away occasionally for student and public demonstrations."

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114 https://wikimili.com/en/Differential_analyser#cite_note-1

115 Irwin, William (July 2009). "The Differential Analyser Explained". Auckland Meccano Guild. Retrieved 2010-07-21. " Archived

116 "Invention of the modern computer". Encyclopædia Britannica . www.britannica.com. Retrieved 2010-07-26.

Between 1947 and 1950, the College of Engineering received four of the first “thinking” machines, promising post-war wonders devised to “take the drudgery out of mathematics.” The four “analyzer” machines are the mechanical differential, electrical differential, network, and thermal analyzers. The amazing new high-speed computing machines (which newspapers have mechanical brains or electronic brains) will tackle problems never solved before. They can predict accurately how a rocket motor will work even before it is built, and will make child’s play out of the complicated statistics of the census or income tax. They can estimate the impact on the nose wheel of an aircraft landing with a force too dangerous to be tried in actual testing, and can predict the speed at which a gas turbine will vibrate according to its design. These machines, along with another called the Automatically-sequenced Digital Computing Machine, which will be part of UCLA’s Institute for Numerical Analysis, serve to establish UCLA as the West Coast “brain center” of the “thinking machine age.”[117]

First Commercial Computer

The original model range was the UNIVAC I (UNIVersal Automatic Computer I), the first commercial computer made in the United States. The main memory consisted of tanks of liquid mercury implementing delay line memory, arranged in 1000 words of 12 alphanumeric characters each. The first machine was delivered on 31 March 1951.

UNIVAC I used about 5,000 vacuum tubes,[118] weighed 16,686 pounds (8.3 short tons; 7.6 t),[119] consumed 125 kW, and could perform about 1,905 operations per second running on a 2.25 MHz clock. The Central Complex alone (i.e. the processor and memory unit) was 4.3 m by 2.4 m by 2.6 m high. The complete system occupied more than 35.5 m2 of floor space.[120] UNIVAC and other first-generation computers were replaced by transistor computers of the late 1950s, which were smaller, used less power, and could perform nearly a thousand times more operations per second. These were, in turn, supplanted by the integrated-circuit machines of the mid-1960s and 1970s. In the 1980s, the development of the microprocessor made possible

[117] https://samueli.ucla.edu/historical-research-highlights/

[118] The vacuum tubes used in the UNIVAC I were mostly of type 25L6, but the machine also used tubes of type 6AK5, 7AK7, 6AU6, 6BE6, 6SN7, 6X5, 28D7, 807, 829B, 2050, 5545, 5651, 5687, 6AL5, 6AN5, 6AH6, 5V4, 5R4, 4D32, 3C23, and 8008.

[119] Weik, Martin H. (March 1961). "UNIVAC I". ed-thelen.org. A Third Survey of Domestic Electronic Digital Computing Systems.

[120] https://en.wikipedia.org/wiki/UNIVAC_I

small, powerful computers such as the personal computer, and more recently the laptop and mobiles hand-held computers.[121]

Figure: Build in display contact lens, Source/MojoLENS

MojoLENS[122]

Meet Mojo Lens, a smart contact lens with a built-in display that gives you timely information without interrupting your focus. By understanding your real-world context, Mojo Lens provides relevant, eyes-up notifications and answers. Designed by optometrists, technologists, and medical experts, Mojo Lens gives you the knowledge you need—exactly when it's needed.

Mojo is dedicated to helping individuals reach their highest potential in work, play, and life while staying connected to people and events in the real world. Mojo is dedicated to helping individuals reach their highest potential in work, play, and life while staying connected to people and events in the real world.

In building Mojo Lens, Mojo has developed many industry-first technologies:

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121 UNIVAC, the first commercially produced digital computer, is dedicated History.com Editors HISTORY URL, https://www.history.com/this-day-in-history/univac-computer-dedicated

122 https://www.mojo.vision/

At the heart of Mojo Lens is our 14,000 pixel- per-inch MicroLED display. Measuring less than 0.5mm in diameter with a pixel-pitch of 1.8 microns, it is the world's smallest and densest display ever created for dynamic content.

Mojo Vision has developed custom application specific integrated circuit (ASIC) designs for Mojo Lens that incorporate a 5GHz radio and ARM Core M0 processor that transmit sensor data off the lens and stream augmented reality (AR) content to the MicroLED display. Lens has a custom-configured accelerometer, gyroscope, and magnetometer that continuously track eye movements so that AR imagery is held still as the eyes move. Mojo Lens uses a proprietary power management system that includes medical-grade micro-batteries and a Mojo-developed power management integrated circuit. It is controlled with a unique and intuitive interface based on eye tracking that allows users to access content and select items without hand or gesture-based controllers, just the natural movement of the eyes.

Brain Computer Interaction

Mind Meld

Researchers at the University of Washington in Seattle say they would like to give humans that kind of brain-to-brain interaction, and have demonstrated a baby step toward that goal. In a set of experiments described in the journal Scientific Reports, the researchers enabled small groups of people to communicate collaboratively using only their minds.

Researchers at the University of Washington in Seattle say they would like to give humans that kind of brain-to-brain interaction, and have demonstrated a baby step toward that goal. In a set of experiments described in the journal Scientific Reports, the researchers enabled small groups of people to communicate collaboratively using only their minds.[123]

In the experiments, participants played a Tetris-like video game. They worked in groups of three to decide whether to rotate a digital shape as it fell toward rows of blocks at the bottom of the screen.

BCI systems (human oriented; computer oriented; mutually oriented systems)

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[123] https://spectrum.ieee.org/video-game-players-electronically-connect-their-brains#toggle-gdpr

Generally , a BCI is a system that allows one to interact with a computing device by means of signals emanating directly from the brain. There are two basic ways of trapping brain signals: invasive and noninvasive. Whereas invasive methods require the placement of sensors connected to the brain inside the scull. Invasive technology is becoming increasingly sophisticated, but brain prosthetics in not a viable option of this research. The most viable non-invasive option for tapping the brain for BCI is currently the EEG.

Regarding an research and article by Eduardo Miranda [124],[125]

It is possible to identify three categories of BCI systems:

1. User oriented: BCI system in which the computer adapts to the user. Metaphorically speaking, these systems attempt to read the EEG of the user in order to control a device. For example, Anderson and Sijercic (1996) reported on the development of a BCI that learns how to associate specific EEG patterns from a subject with commands for navigating a wheelchair.

2. Computer oriented: BCI systems in which the user adapts to the computer. These systems rely on the capacity of the users to learn to control specific aspects of their EEGs, affording them the ability to exert some control over events in their environments. Examples have been shown where subjects learn how to steer their EEG to select letters for writing words on a computer screen.[126]

3. Mutually oriented: BCI systems that combine the functionalities of both categories; the user and computer adapt to each other. The combined use of mental task pattern classification and biofeedback-assisted on line learning allows the computer and the user to adapt. Prototype systems to move a cursor on the computer screen have been developed in this fashion.[127]

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124 Miranda, Eduardo & Brouse, Andrew & Boskamp, Bram & Mullaney, Hilary. (2005). Plymouth brain-computer music interface project: Intelligent assistive technology for music-making.

125 Miranda, Eduardo & Durrant, Simon & Anders, Torsten. (2008). Towards Brain-Computer Music Interfaces: Progress and Challenges. 1 - 5. 10.1109/ISABEL.2008.4712626.

126 Birbaumer, N., Ghanayin, N., Hinterberger, T., Iversen, I., Kotchoubey, B., Kubler, A., Perelmeouter, J., Taub, E. and Flor, H. (1999), “A spelling device for the paralysed”, Nature 398:297-298

127 Peters, B.O., Pfurtscheller, G. and Flyvberg, H. (1997), “Prompt recognition of brain states by their EEG signals”, Theory in Biosciences 116:290-301.

Brain Sensing VR technology

LOOXID

Looxid Labs is a virtual reality (VR) healthcare startup. They harnessed the advantages of VR technology to disrupt cognitive health decline and improve the lives of older adults. They have developed an AI-driven cognitive health care data platform which can be used to detect early signs of cognitive impairment through the analysis of users' biosignals. Examples of these signals include eye tracking and EEG data, which are monitored through the VR system. Ultimately, we aim to make technology to predict and to prevent cognitive impairment with efficiency. LUCY is an early screening of dementia, which improves the quality of life.

LUCY is a sensor-based VR system that allows early detection of cognitive decline in the elderly. LUCY exploits VR games designed to assess several cognitive domains and EEG sensors attached to VR headsets to collect brain dynamics data during the cognitive tasks. Based on game performances and EEG characteristics, LUCY provides an easily understandable report describing your cognitive status.[128]

Figure: Neurable EEG strap attached to HTC Vive / Source: Neurable

[128] https://looxidlabs.com/about

Neurable

In 2017, Neurable unveiled a hardware device, called the Developer Kit 1 (DK1), that connected with HTC's groundbreaking Vive virtual reality (VR) product. We used VR as a vehicle to demonstrate key concepts and prove early applications of brain-computer interfaces. We envisioned a roadmap for achieving a world with mental control of technology and affective computing (computers that can detect emotion), two new dimensions for how humans interact with machines. Two sides of the same BCI coin.[129]

Neurable learned from the potential custmes feedback as they asked mainly about how to make sense of how the brain acts. The Neurable team tackle the problem of reliably measuring cognitive states while simultaneously offering new ways to control devices. We could do all of this outside of the laboratory with a form factor that was easier to use, lower cost, and more familiar to most people than VR.

Neurable then spent a year in R&D-mode, creating cognitive measurement tools and developing a way to measure the brain's emotional state, specifically designed for attention, which could be even more specifically defined and understood as "cognitive load."[130] Parallel to this development, virtual reality also found a foothold in the enterprise simulation training market, offering safer and more cost-effective methods to train employees. For example, training an electric utility employee to repair a powerline becomes much safer if the trainee is on the ground, in VR, and has the freedom to make mistakes without the potential for injury. The key limitation of VR simulations is that they lack feedback about how the trainee learns. Does she know the material, or did she just get lucky? Neuroscience can help with that! Neurable quickly found significant interest and co-investment in the military sector, so we partnered to commercialize a solution.[131]

Neurotechology can achieve great things but are largely confined to laboratory settings because they are really hard to use and even more difficult to interpret. Non-invasive BCIs (systems that don't involve implanting things in people's heads) are extremely limited in what they can measure and those measurements are even more difficult to understand. We have to innovate to make

129 Molder, A., https://neurable.com/blog/were-neurable

130 https://spectrum.ieee.org/brainy-startup-neurable-unveils-the-worlds-first-braincontrolled-vr-game

131 Molder, A., https://neurable.com/blog/were-neurable

neurotechnology simple and accessible. The Neurable team has innovated in the fields of mathematics, neuroscience, materials science, psychology, and more to make this happen, to accomplish our vision, to make the everyday BCI.[132]

[132] Molder, A., https://neurable.com/blog/were-neurable

2. Advanced Architecture

Advanced Architecture AA

Computers, digital media, liberate the duality of concepts of space in human civilisation. People immerse inside the space as in the virtual reality environment. Moreover, many people already spend hours a day or even longer to “live in” a virtual place called cyberspace where the spatial experience, human-environment interaction, and human-human interaction differ heavily from those in physical space. People could arbitrarily hyper-link to other places like in scenarios of sci-fi novels; the organisation of cyberspace extends the current rigid adjacency of space. The new space of this kind may be called digital space or virtual space. This new space is between mental and physical spaces because it provides designers with not only unlimited imaginability of mental space but also live-inside perception of physical space. A new concept of space of mankind is thus generated (Liu et al. 2002; Wan et al. 2002).

The initial dual concept of space in architectural history has liberated. A new trine concept of space is evolving due to digital design media. From now on, people are able to walk back and forth in mental, physical, and digital-virtual space as they want. New media create new spaces; new spaces in turns create new architecture (Liu, 2003) a digital architecture.

Informed Intelligent Architecture IIA and Algorithm Aided Architecture AAA

The technical possibilities that new information and computational technologies offer design as well as building processes have consequences that are not only technical. Thinking, drawing, and imagining are deeply influenced by techniques that determine new ways of defining things and their relations. The power of algebraic and geometric computerised algorithms allows us to design buildings in a completely different way from the past.[133]

Writing and coding represents a radical revolution for architectural design, which depends on the one hand on the computational power of information technologies and on the other hand on the power of representation of computer graphics hardware and interface.

133 Springer International Publishing AG 2018 M. Hemmerling and L. Cocchiarella (eds.), Informed Architecture, The Algorithms-Aided Design (AAD)

Architectural Intelligence

An Evolutionary Architecture- John Frazer 1995. In the preface of the same titled book Gordon Pask mentioned that the fundamental thesis is that of architecture as a living, evolving thing. And, truly in the recent days is evident that we will depart this way. Our culture's striving towards civilisation is manifested in the places, houses and cities that it creates. As well as providing a protective shells, these structures also carry symbolic value, and can be seen as being continuous with and emerging from the life of those who inhabit the built environment. Architectural Intelligence integrates the natural processes and depart from the symbolical and metaphorical tectonic designing.

An Evolutionary Architecture investigates fundamental form-generating processes in architecture, paralleling a wider scientific search for a theory of morphogenesis in the natural world. It proposes the model of nature as at the generating force for architectural form. The profligate prototyping and awesome creative power of natural evolution are emulated by creating virtual architectural models which respond to changing and dynamic environments. Successful developments are encouraged and evolved. Architecture is considered as a form of artificial life, subject, like the natural world, to principles of morphogenesis, genetic coding, replication and selection. The aim of evolutionary architecture is to achieve in the build environment the symbiotic behaviour and metabolic balance that are characteristic to the natural environment.

In nature it is only the genetically coded information of form which evolves, but selection is based on the expression of this coded information in the outward form of an organism. The codes are manufacturing instructions, but their precise expression is environmentally dependent, but as in the real world model it is only the code script which evolves.

Future of Architectural Intelligence

The future emerges from the interaction of billions of current activities, natural and artificial.[134] The future architecture is capable of perceptual interaction with the environments, and stimulate construction and growth with regard to the needs of natural and artificial aspects of the specific environment. Architectural Intelligence is a set of evolutionary mechanisms that has a capability to

[134] Rzevski, George, and Petr Skobelev. 2014. Managing Complexity. Southampton Boston: WIT Press/Computational Mechanics.

adapt the architectural organism to the new environmental situation or behavioural patterns of it's symbionts, in a sort-term or long-term interactions. The Architectural Intelligence is both adapting, changing and accommodating the environmental dynamic and behavioural conventions. The architectural intelligence is taught by its architect. The intelligence is encoded in a script of a neural networks models that are capable of rewriting existing code protocols, and therefore actively address acute issues of architecture for effective and dynamic adaptability. This architectural approach proposes a theory of architectural adaptive systems. Intelligence can be seen as a form of adaptation in which knowledge is constructed by each individual through two complementary processes of assimilation and adaptation.[135] Adaptation is an evolutionary process as a result of which the body better adapts to a dynamically changing environment. If an organism cannot move or change enough to maintain its long-term viability, it will obviously go extinct.

In this perspective, Architectural Intelligence is a set of methods that adapt architecture to the environmental and social changes and instability. Architectural Intelligence is a method of solving architectural problems. This approach propose the use of computer science techniques, in particular deep learning and meta-learning, to represent and analyze complex architectural and urban phenomena and to find and generate optimal spatial forms. Modelling complex natural processes requires computer science and it is no coincidence that the development of computer science has been largely shaped by the construction of computer models to simulate natural processes. Based on the developed models, we generate intelligent architectural structures that provide sustainable environmental conditions for individuals and communities based on their spatial experience and behavior. Predictions generated from models with the use of neural networks actively solve difficult problems of architecture in order to effectively adapt to dynamic changes in the environment.[136]

2.1 Data, Information and Representation

2.1.1 Data Gathering

[135] (Jean Piaget).

[136] Unpublisherd notes, Kotnour & Lisek, 2020

This chapter considers the time-related processing of complex sounds relevant to musical analysis. Imaging of human auditory brain stem processing is technically limited in functional imaging techniques, including PET, fMRI, MEG and EEG.

The studies of humans with brain lesions and functional imaging provide convergent evidence for the existence of a neural substrate for the processing of sound sequences that is hierarchal in organization. The pathway up to and including the primary auditory cortices may provide a sufficient mechanism for the processing of spectro-temporal features of individual sounds.

The features of individual notes are analyzed in the pathway up to and including the auditory cortices, while higher-order patterns formed by those features are analyzed by distributed networks in the temporal lobe and frontal lobes distinct from the auditory cortices.

All sound is processed by mechanisms for the analysis of simple acoustic features such as intensity, frequency, onset, the neural processing of complex sound features, complex acoustic features, such as patterns of these simple features as a function of time, and semantic features learned association of sound patterns and meanings.

For the analysis of music, analysis of temporal features is likely to be particularly important, although I would certainly not dismiss the role of spectral or spatial analysis. Temporal analysis can be considered at different levels that Peretz call the fine temporal structure and higher-order temporal structure.[137]

In particular, I would point out approaches based on the modulation transfer function. Here, responses to modulation of the sound amplitude or frequency are considered as continuous functions of modulation rate. This approach has been used in human psychophysical work, evoked-potential work, and functional imaging work.

The experimental work of the architectural intelligence model operates with the evoked potential approach to observe, record and process the neural activity signals and responses to the

[137] Peretz, Isabelle, and Robert J. Zatorre. *The cognitive neuroscience of music*. Chapter 11, The neural processing of complex sounds page 168, Timothy D. Griffiths. Oxford New York: Oxford University Press, 2003.

complex sound environments with many features in the each sound signal, that on some levels of sound complexity reaching complexity of noise. The experiment described in the part III of the thesis is simulation of a complex sound and dynamic sound environment.

In the human auditory system much work on mechanisms of temporal processing, particularly in the case of music, has focused on the auditory cortex and cortical networks involving the auditory cortices. However, the ascending auditory pathway (Figure 11.2) affords an extensive mechanism for the processing of complex signals before the cortex is reached.

The data that are entering, or outgoing the simulation model are recorded to the large databases for a further processing. The complex sound features are written with a spatio-temporal information as well as the data recorded during the experimental work with evoked-responces, captured by EEG Neurocap.

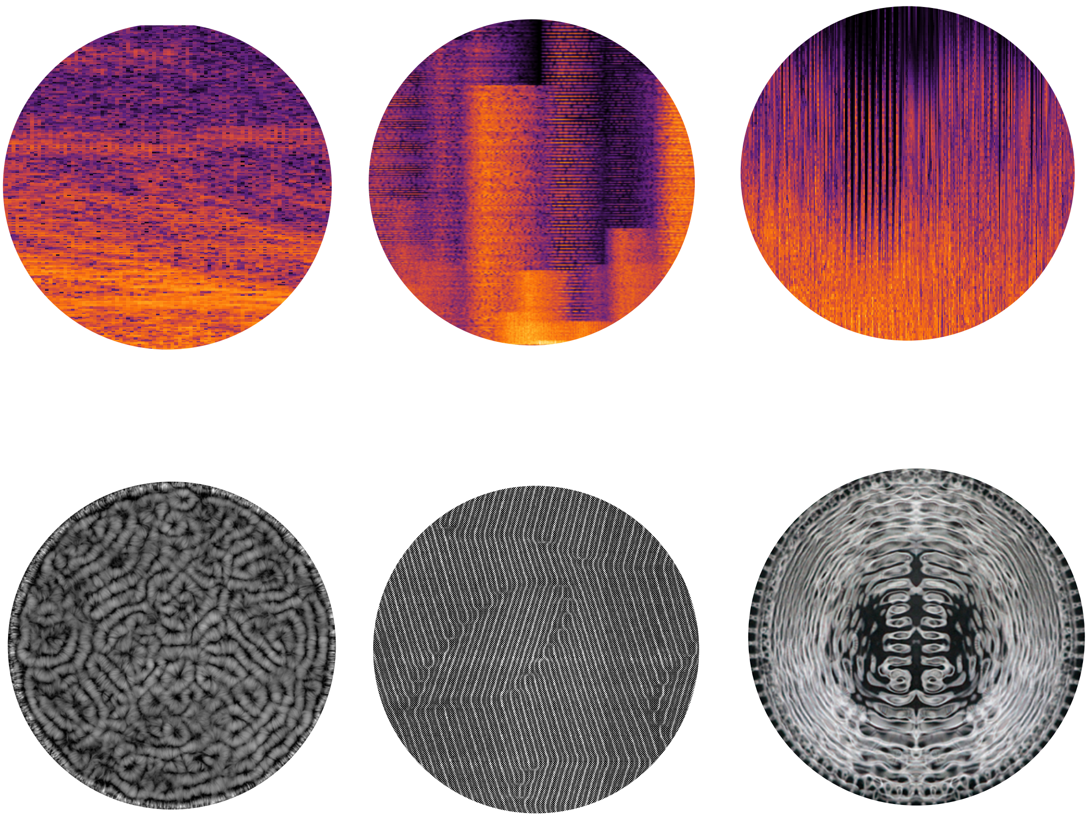

Figure: Authors soundscapes and spectro-temporal patterns, and selected spatio-temporal patterns in nature processes

2.1.2 Spatio-Spectro—Temporal features

Concerning signals in sound signals or neural activity the large dynamic matrices of multivariable data, can be found two types of patterns in data and their features. A sound signal represents a spectro-temporal evolving process in time. Several sources of signals located at different locations, represent a spatio-temporal process.

Pattern formation is about the visible orderly outcome of self-organization and the common principles behind similar patterns in nature. Pattern formation are complex organizations of particles fates in space and time.

Pattern formation in nature is decided by genes. They have the role of morphogenesis, which is about the creation of similar genes through diverse anatomies.

Brain Waves and Sound Waves

The *Spectro-Temporal Receptive Field* or *Spatio-Temporal Receptive Field* (STRF) of a neuron represents which types of stimuli excite or inhibit that neuron.[138] *Spectro-Temporal* refers most commonly to audition, where the neuron's response depends on frequency versus time, while *Spatio-Temporal* refers to vision, where the neuron's response depends on spatial location versus time. Thus they are not exactly the same concept, but both referred to as STRF and serving a similar role in the analysis of neural responses.

Spectro-Temporal features of complex environments

The Spectro-Temporal features is sort of intensity as a function of time and frequency.

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[138] Jean Pierre Richard; Hans-Joachim Leppelsack; Martine Hausberger (1995), "A rapid correlation method for the analysis of spectro-temporal receptive fields of auditory neurons", Journal of Neuroscience Methods, 61 (1–2): 99–103, doi:10.1016/0165-0270(95)00029-T, PMID 8618431, S2CID 40813974

The *Spectro-Temporal Receptive Field* (STRF) of an auditory neuron is a time-frequency measure of the dynamic responses of an auditory neuron to impulsive energy delivered at various frequencies. As such, it gives simultaneously two types of information about the neuron. The first is its frequency tuning, or more specifically which frequencies excite the cell best and which inhibit it. The other is the nature of its temporal response, i.e., whether it is sustained in time or is rapidly adapting. This measure is linear and takes the stimulus spectrogram as its input and hence is often found to be useful in predicting responses of a neuron to unseen stimuli.

The Spectro-Temporal Receptive Field (STRF) of an auditory neuron has been introduced experimentally on the base of the average spectrotemporal structure of the acoustic stimuli which precede the occurrence of action potentials. [139]

Coding Spectro-Temporal Environments

This family of methods is useful when the spikes are time locked to those acoustic events that are relevant to the neuron. Otherwise, averaging may actually remove the stimulus features that excite the neurons. When the stimulus set has a rich correlation structure, averaging the stimuli that precede spikes usually reveals structures that characterize the stimulus itself (regardless of the responses).

Spatio-Temporal features of complex environments

The Spatio-Temporal features relating both space and time, or to space-time, therefore extending the traditional tree dimensional space with dimension of time. In contrast to static features of pure spatial patterns, the spatio-temporal features give us knowledge and full complexity of spatio-temporal patterns that are observed only over time.

Spatio-temporal patterns appear almost everywhere in nature, and their description and understanding still raise important and basic questions. There has been made definite progress in the modelling of instabilities, analysis of the dynamics in their vicinity, pattern formation and

[139] Aertsen, A.M.H.J., Johannesma, P.I.M. The Spectro-Temporal Receptive Field. Biol. Cybern. 42, 133–143 (1981). https://doi.org/10.1007/BF00336731

stability, quantitative experimental and numerical analysis of patterns, and so on. The universal behaviours of complex systems have been determined. The wide interdisciplinary of a field of nonlinear science or science of complexity. The methods of nonlinear dynamics and instability theory could provide useful tools for understanding spatio-temporal pattern formation in other fields such as biology or materials science and architecture.

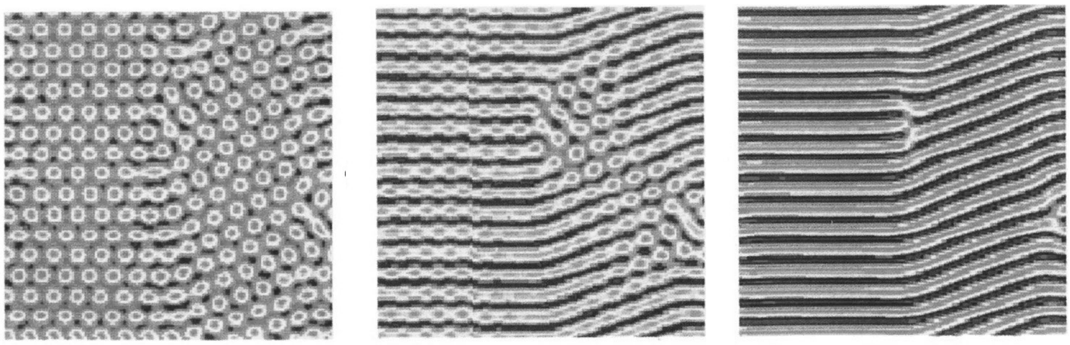

Figure: Spatio-Temporal transition in dynamic environment, from left to right, pattern formation of vibrating particles

One of the most intriguing aspects of the complex dynamics that govern natural phenomena is perhaps the occurrence of instabilities and symmetry breakings leading to the formation of coherent *spatio-temporal* structures on macroscopic scales. Understanding the origin of *spatio-temporal* order in open systems far from thermal equilibrium - and understanding the selection mechanisms of the spatial structures and their symmetries - is now a major theme of theoretical and experimental research.[140]

The pattern-forming instabilities have not always been recognised as a natural aspect of complex systems, despite the fact that some of them have been studied for many years. The complex structures are now observed in an increasing number of systems and their links with numerous biological phenomena are clearly recognised. The experiments in this field also shown that these structures arise in specific kinetic schemes including autocatalytic and regulatory processes competing with transport phenomena. Hence, reaction-diffusion systems form an important class of systems able to display *self-organization* phenomena and produce various types of

140 Walgraef, D. (1997). Introduction. In: Spatio-Temporal Pattern Formation. Partially Ordered Systems. Springer, New York, NY. https://doi.org/10.1007/978-1-4612-1850-0_1

spatio-temporal patterns. [141] Even living organisms have long been considered as the result of chance rather than of necessity.

From the theoretical point of view, either in hydrodynamics, chemistry, optics, or materials science, the most important problems are related to the determination of the properties of the instabilities and of the formation, selection, and stability of the associated *spatio-temporal* patterns. Since these systems are described by nonlinear partial differential equations, these problems are very difficult to solve because it is usually impossible to obtain analytical solutions for these equations. However, in the 1970s, general techniques were developed to study approximate solutions in the vicinity of the instabilities.

This thesis, and especially its experimental part, works with the knowledge that similar phenomena appear in very different systems (e.g. spiral waves in chemical systems, but also in the cortex or cardiac activity, during the aggregation of microorganisms; convective rolls associated with hydrodynamic instability in normal fluids and liquids) shows that they are not induced by microscopic properties of systems, but that they are triggered by collective effects involving a large number of individuals (atoms, molecules, cells), thus also sound particles, granules, and the discharge of neural networks of the brain in response to sound stimuli.

Figure: Anechoic chamber for surround sound - for the purposes of this thesis author created the virtual space for Surroundsound in PureData and Unreal Engine, see Apendix A on authors GitHub

141 Daniel Walgraef (auth.) - Spatio-Temporal Pattern Formation_ With Examples from Physics, Chemistry, and Materials, (Partially Ordered Systems) Science-Springer-Verlag New York (1997)__

Ambisonic and Surround sound and Spatio-Spectro-Temporal data for the dynamic environment model

Spherical Coordinate System

For the spatial sound array, the following conventions are used when defining the spherical coordinate system:

- Vertical Angle, Elevation (d): is the angle in the vertical dimension. In degrees it ranges from 0 to 180. The 0 degrees direction points away from the top of the spherical array (the opposite side from where the shaft mounts to the array; towards the ceiling in a typical arrangement). The 90 degrees direction is the horizontal plane, and the 180 degrees direction is in the direction of the shaft (typically towards the floor).

- Horizontal Angle, Azimuth (θ): is the angle in the horizontal plane. It ranges from 0 to 360 degrees. The 0 degrees direction aligns with the “mh acoustics” logo on the shaft of the array. The angle increases in the counter-clockwise direction looking from the top of the array.

The formula for transforming coordinates are as follows:[142] [143]

$$x = r\cdot\cos(\delta)\cos(\theta) \qquad y = r\cdot\cos(\delta)\sin(\theta) \qquad z = r\cdot\sin(\delta)$$

$$r = \sqrt{x^2 + y^2 + z^2} \qquad \theta = \arctan(y/x) \qquad \delta = \operatorname{arccot}\left(\frac{\sqrt{x^2+y^2}}{z}\right)$$

Brain Activity and Spatio-Spectro-Temporal data for dynamic environment model

Spatio-spectro-temporal data (SSTD) are the most common types of data collected in many domain areas, including engineering, bioinformatics, neuroinformatics, ecology, environment,

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142 http://write.flossmanuals.net/csound/b-panning-and-spatialization/

143 https://www.semanticscholar.org/paper/REAL-TIME-3-D-AMBISONICS-USING-FAUST-%2C-PROCESSING-%2C-Lecomte-Gauthier/48d72bf7f65d8c15b110a0d08e0d5cef28fb4bbd

medicine, economics, etc. However, there is lack of methods for the efficient analysis of such data and for spatio-temporal pattern recognition (STPR).

The brain functions as a spatio-temporal information processing machine and deals extremely well with spatio-temporal data. Its organisation and functions have been the inspiration for the development of new methods for SSTD analysis and STPR by profesor of mathematics Nikola Kasabov. The brain-inspired spiking neural networks (SNN) are considered the third generation of neural networks and are a promising paradigm for the creation of new intelligent ICT for SSTD.

This new generation of computational models and systems are potentially capable of modelling complex information processes due to their ability to represent and integrate different information dimensions, such as time, space, frequency, and phase, and to deal with large volumes of data in an adaptive and self-organising manner. Nikola Kasabov reseraches various methods and systems of SNN for SSTD analysis and STPR, including single neuronal models, evolving spiking neural networks (eSNN) and computational neuro-genetic models (CNGM). Software and hardware implementations and some pilot applications for audio-visual pattern recognition, EEG data analysis, cognitive robotic systems, BCI, neurodegenerative diseases, and others are discussed.[144]

The brain spatio-spectro temporal data might look as a large arrays of seemingly random numbers, without much to say about architectural space or sound scape environment. However, this type of data is essential for a better idea and modelling of the dynamic environment. As one of the option we have is to track correlations of two spatio-spetro-temporal data fields (arrays of data), while we can make expert observation of these correlations and receive interesting outcomes. These interpretations can be misleading while we can avoid some important factors and scales that could change the whole model behaviour. Model of the dynamic environment proposed for architecture in this thesis responds to this limitation of direct data subjective expert interpretation of acquired data, the proposed dynamic model works continuously, reevaluates and predict the input and output data and organise them.

[144] Kasabov N. (2012) Evolving Spiking Neural Networks and Neurogenetic Systems for Spatio- and Spectro-Temporal Data Modelling and Pattern Recognition. In: Liu J., Alippi C., Bouchon-Meunier B., Greenwood G.W., Abbass H.A. (eds) Advances in Computational Intelligence. WCCI 2012. Lecture Notes in Computer Science, vol 7311. Springer, Berlin, Heidelberg

Clustering is a fundamental data processing technique. Clustering aims at objectively organise data samples into homogenised groups, where the data samples within a group are similar. So far many clustering methods have been developed to identify structures in different data types, such as static, temporal, etc. Data is static when the feature values do not change over time, and it is time series (temporal) if the features change their values over a continuous time. With respect to different data types, clustering methods differ significantly in the notion of the similarity or distance measures.

Massive amount of temporal data (time series data) has been recorded so far in various areas, such as electronic, video/audio, biologic, neurology, etc. In case of clustering of such data, given a set of individual time series values, the objective is to group similar patterns into the same cluster. This task demands a measure notion to estimate the level of similarity between time series. However, the known Euclidean distance and other typical measures used for non-temporal data are unsuitable metrics to evaluate the similarity between time series, because they are unable to deal with temporal interaction between time series data features.
The mayor inspiration and state of art knowledge up to day was taken from the model of NeuCube, a computational framework with dynamic clustering of spatio-temporal connectivity and spiking activity of the spiking neurons in a NeuCube model, while it is learning from streaming data.[145]

While Kasabov defines the common goals for the NeuCube framework

- to detect similar spatio-temporal patterns of changes in the streaming data, which are dynamically generated with respect to the interaction between input variables. The dynamic visualisation of the clusters captures the time in which a cluster is created and it demonstrates how this cluster is changed over time. It enables us for the first time to study the dynamics of such clusters.

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[145] Doborjeh, M.G., Kasabov, N. & Doborjeh, Z.G. Evolving, dynamic clustering of spatio/spectro-temporal data in 3D spiking neural network models and a case study on EEG data. *Evolving Systems* **9,** 195–211 (2018). https://doi.org/10.1007/s12530-017-9178-8

- to understand hidden spatio-temporal patterns of changes in the data by pursuing the trend of the cluster creation. For the case study shown in the paper, this relates to brain activities.

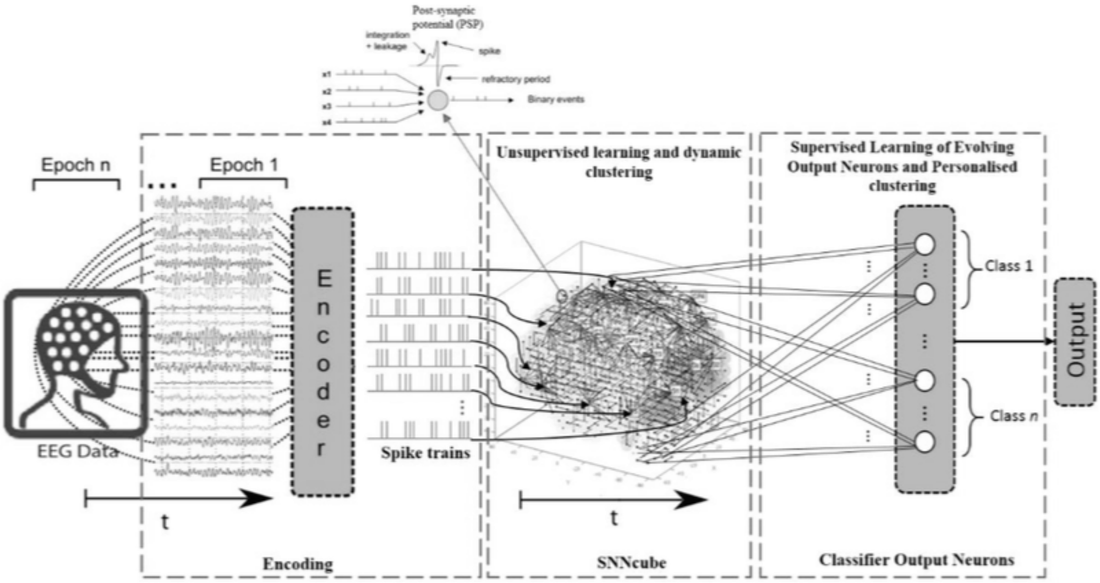

Figure: Kasabov's schematic block diagram of the NeuCube Architecure illustrated of EEG brain streaming data

The NeuCube-based SNN architecture consists of: input data encoding module; that encodes multivariable continuous temporal stream data into spike trains; a 3D recurrent SNN cube (SNNcube), where input data are mapped and learned in an unsupervised mode; and an SNN classifier that learns in a supervised mode to classify the spatio-temporal patterns of the SNNcube activities which represent patterns from the input data (Kasabov 2007; Kasabov 2012; Kasabov 2014; Kasabov et al. 2013). The neuronal clusters evolved in the SNNcube during unsupervised learning can be also statistically compared in terms of the size (number of neurons that belong to each cluster) and also in terms of the cluster creation time. A bigger cluster contains larger number of spiking neurons around the centre, which means more spikes transmitted via this centre to the SNNcube.

In this thesis it is not intended for modelling the brain in its precise structural and functional complexity, but rather for borrowing spatio-temporal information processing principles from the brain for the creation of brain-inspired AI as general spatio-temporal data machines for deep learning and deep knowledge representation in time-space for the form of Architectural Intelligence model that operate in a dynamic environment such as sound-scape.

2.1.1.2 Spatial Sound Cognition

On Emotion and perception in Architecture

From Spinosa, we learn that the most writers on the emotions and on human conduct seem to be treating rather of matters outside nature than of natural phenomena following nature's general laws.[146]

But no one, so far as I know, has defined the nature and strength of the emotions, and the power of the mind against them for their restraint.[147] Everyone shapes actions according to emotion, those who are assailed by conflicting emotions know not what they wish; those who are not attacked by any emotion are readily swayed this way or that.[148]—Thus we see, that the mind can undergo many changes, and can pass sometimes to a state of greater perfection, sometimes to a state of lesser perfection. These passive states of transition explain to us the emotions of pleasure and pain.

By *pleasure* Spinoza suggest following propositions: "*a passive state wherein the mind passes to a greater perfection*". By *pain* Spinoza means: "*a passive state wherein the mind passes to a lesser perfection.*" Further, the emotion of pleasure in reference to the body and mind together I shall call *stimulation* (titillatio) or *merriment* (hilaritas), the emotion of pain in the same relation I shall call *suffering* or *melancholy*.[149] Again, as everyone judges according to his emotions what is good, what bad, what better, and what worse, it follows that judgments may vary no less than their emotions.[150]

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146 SPINOZA, BENEDICT, THE ETHICS (Ethica Ordine Geometrico Demonstrata) translated by R. H. M. Elwes Part III: Of the Power of the Understanding, or of Human Freedom A PENN STATE ELECTRONIC CLASSICS SERIES PUBLICATION, Copyright © 2000 The Pennsylvania State University

147 Ibid.

148 Ibid.

149 Ibid.

150 Ibid.

Emotion, which is called a passivity of the soul, is a confused idea, whereby the mind affirms concerning its body, or any part thereof, a force for existence (existendi vis) greater or less than before, and by the presence of which the mind is determined to think of one thing rather than another.[151]

But the idea which const tunes the reality of an emotion must denote or express the dis position of the body, or of some part thereof, because its power of action or force for existence is increased or diminished, helped or hindered. But it must be noted that, when I say *"a greater or less force for existence than before,"* it does not mean that the mind compares the present with the past disposition of the body, but that the idea which constitutes the reality of an emotion affirms something of the body, which, in fact, involves more or less of reality than before.[152]

Human Sensing, Artificial and Augmented Sensing

"For twenty-five centuries, Western knowledge has tried to look upon the world. It has failed to understand that the world is not for the beholding. It is for hearing. It is not legible, but audible."
(oppening of a book Noise - The Political Economy of Music, Jacques Atalli, 1977)

The human brain deals mainly with 5 sensory modalities: vision, hearing, touch, taste and smell. Each modality has different sensory receptors. After the receptors perform the stimulus transduction, the information is encoded through the excitation of neural action potentials. The information is encoded using average of pulses or time interval between pulses. This process seems to follow a common pattern for all sensory modalities, however there are still many unanswered questions regarding the way the information is encoded in the brain.

Hearing

The human auditory system provides information about sounds (air vibration) and their location. This is useful for communication and safety, for example, as we can hear a car moving towards

151 Ibid.

152 Ibid.

us.[153] Our ears act as multiple band filters and it is the harmonic content of sound and its change over time that allows us to identify a range of different instruments and voices.[154] The human auditory system does not support equal sensitivity to different frequencies at low volume. This was originally described as the Fletcher Munson Curve[155], but more recent measurements have given us Equal Loudness Contours. Regarding that we decode emotions in a sound of voice that are important part of communication.

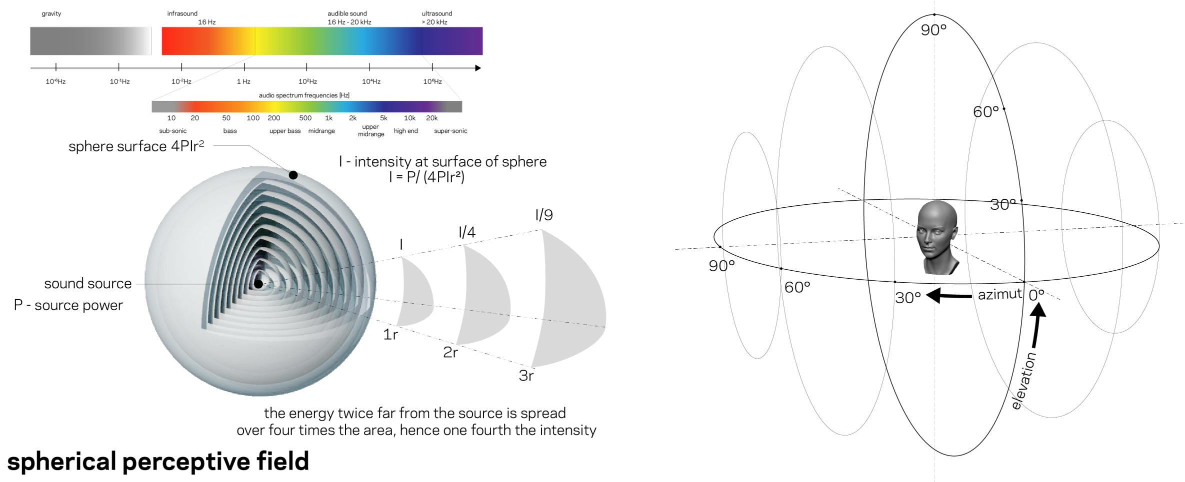

Figure: Spherical Receptive Field, diagram by author, Karolína Kotnour

Audition poses a particular challenge to cognitive neuroscience: first, the “bottom-up” processes of acoustically decoding and neurally encoding the auditory signal along the central auditory pathways are not well understood. Second, humans cope surprisingly well with various sorts of occlusions, deletions, and degradations in their auditory input—in phone lines and at noisy parties, in chronic hearing damage, or, most drastically, when living with a cochlear implant.[156]

Vision

153 Varsani, Puja et al., Sensorial Computing, Chapter 15, p. 265-284 by Springer International Publishing AG, part of Spring Nature 2018 - Filimowicz, Michael, and Veronika Tzankova(eds.), New Directions in Third Wave Human-Computer Interaction: Volume 1 - Technologies, Human–Computer Interaction Series, https://doi.org/10.1007/978-3-319-73356-2_15

154 Bregman A (1990) Auditory scene analysis: the perceptual organization of sound. MIT Press, Cambridge, MA/London

155 Fletcher H, Munson WA (1933) Loudness, its definition, measurement and calculation. Bell Labs Tech J 12:377–430

156 https://www.cbs.mpg.de/former-groups/auditory-cognition

Regarding Varsani[157] among all human senses, vision is by far the one which involves the most neural networks in the brain and consider it as it is certainly due to its importance and complexity, referring to an recent animal and human vision research, that describe that what we perceive as an image is the product of very complex, distributed, and interdependent cognitive processes involving most of the brain. The fact that that vision is not a deterministic process will be explained in Chapter Brain Inspired AI and Machine Learning. Varian et al. explains that the same scene can elicit substantially different responses depending on the subject internal state and external context. Some of the factors affecting visual perception are environmental context, task, concurrent stimuli, social conditionings, attention allocation, personal experience and knowledge, motor goals, and others.

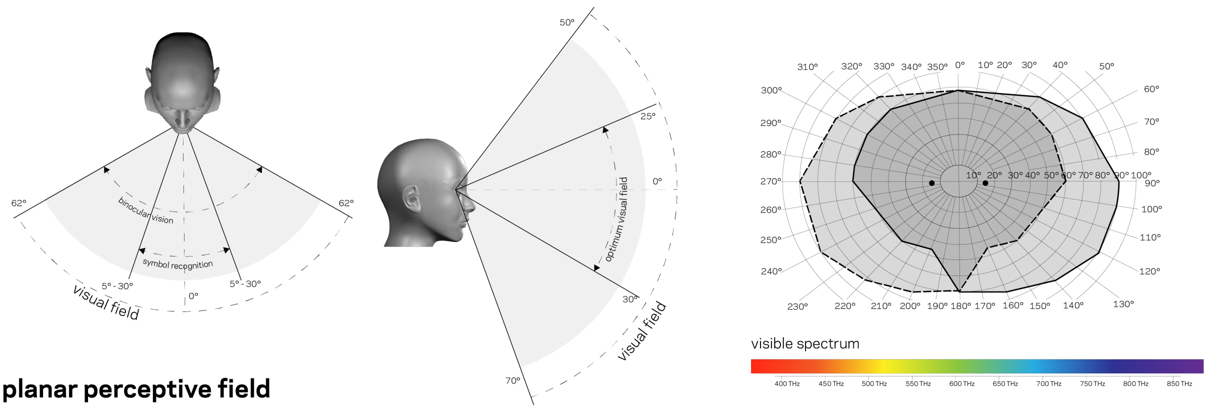

Figure: Planar Receptive Field, diagram by author, Karolína Kotnour

As all other senses, vision is not immune to cross-modal effects. On the contrary, concurrent stimuli from other senses, and priming and inhibitory effects are directly affecting visual perception by changing the focus of attention or biasing perceptual goals, or inhibiting or enhancing responses according to the congruence or incongruence of concurrent stimuli.[158] For what concerns social interaction, vision is certainly a major factor in establishing and successfully carrying out most human interactions, either personal, professional, or casual. At the same time,

157 Varsani, Puja et al., Sensorial Computing, Chapter 15, p. 265-284 by Springer International Publishing AG, part of Spring Nature 2018 - Filimowicz, Michael, and Veronika Tzankova(eds.), New Directions in Third Wave Human-Computer Interaction: Volume 1 - Technologies, Human–Computer Interaction Series, https://doi.org/10.1007/978-3-319-73356-2_15

158 Varsani, Puja et al., Sensorial Computing, Chapter 15, p. 265-284 by Springer International Publishing AG, part of Spring Nature 2018 - Filimowicz, Michael, and Veronika Tzankova(eds.), New Directions in Third Wave Human-Computer Interaction: Volume 1 - Technologies, Human–Computer Interaction Series, https://doi.org/10.1007/978-3-319-73356-2_15

the social context is one of the main factors in visual perception, strongly affecting attention allocation.[159]

Smell

Our olfactory sense has only really been integrated with electronic devices and media in the geist of the 3rd wave. Suzuki et al. (2014) provide a summary from early experiments in the 1950s to more recent use of sniff cards. The use of smell has largely been associated with limited attempts to enrich perceptual experiences. The human nose is an extremely sensitive organ (McGann 2017). It contains approximately 50 million cells acting as primary receptors.

Taste

The tongue is the primary organ of taste in the gustatory system and it is closely linked to the olfactory system. Its upper surface is covered in taste buds equipped with taste receptor cells (Li et al. 2002). Each taste receptor receives multiple chemical substances creating a single taste.

Touch

Skin is the largest, oldest and most sensitive organ in the human body and is said to be the first medium of communication (Juhani 2014). Covered in 1000’s of nerve endings, dermis is a layer of the skin providing the sense of touch. The brain processes touch via two parallel pathways: the first provides facts such as vibration, pressure, texture, and the second social and emotional information.

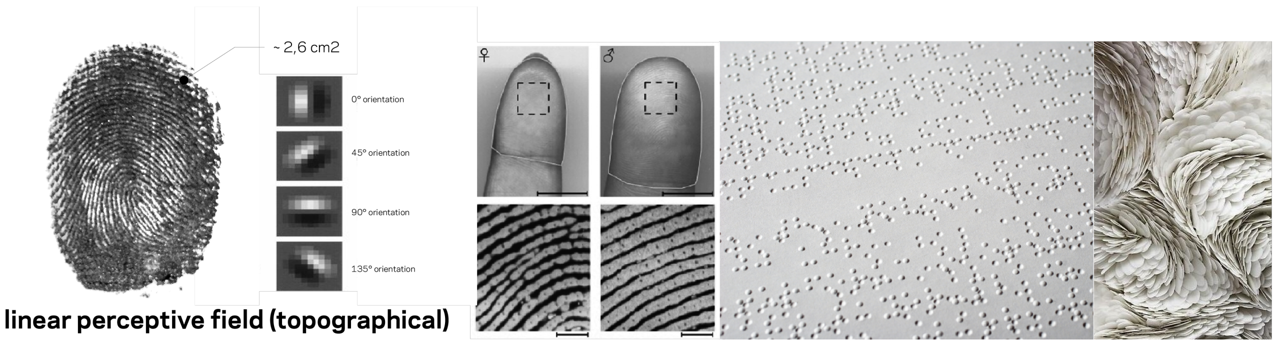

Figure: Topographical receptive field, diagram by author, Karolína Kotnour

Spatial Cognition

[159] Ibid.

"Film's undoubted ancestor is architecture."
Sergei M. Eisenstein

Spatial cognition, our awareness of the surrounding environment, plays a fundamental role in all of our behaviour.[160] John O'Keefe and his colleagues at the University College in London were among the first to identify "place-cells" and their role in creating spatial maps.[161]

Our capacity to learn language, the capability to build a spatial map is innate, but the particular features of the map depend on each person's experience. Spatial cognition, an inherent expression of our basic orienting system, is wrought with emotional, mental, and social implications. We now know that the architecture of each person's brain is unique, and its uniqueness stems in part from the places we experience.[162] What makes a place work its way into our psyche? Can we remember anything outside the context of place?

When we wander through a building or a street, we act precisely like a film spectator absorbing and connecting visual spaces. The changing position of a body in space creates both architectural and cinematic grounds.[163] Architectural frames, like film frames, are transformed by an open relation of movement to events. These movements are practices of space, that is, tangible plots of everyday life. Ultimately, this is how urban experiences, dynamics of space, movement, and lived narrative, embody the effect of the cinema, and its intimate promenades. This research on sound, space and motion ultimately touches on internally mobilised territories of inner landscapes. Like the city, motion pictures move both outward and inward: they journey through the space of the imagination, the site of memory, and the topography of affects. It is this

160 https://www.quantamagazine.org/the-brain-maps-out-ideas-and-memories-like-spaces-20190114/

161 Kandel, E. R. (2006). In Search of Memory: The Emergence of a New Science of Mind. New York: W. W. Norton. Reviewed by Jason A. Kaufman, PhD, Inver Hills Community College, American Journal of Clinical Hypnosis, 52:3, 236-237, DOI: 10.1080/00029157.2010.10401723

162 Arbib, M. (2015). TOWARD A NEUROSCIENCE OF THE DESIGN PROCESS. In Robinson S. & Pallasmaa J. (Eds.), Mind in Architecture: Neuroscience, Embodiment, and the Future of Design (pp. 75-98). Cambridge, Massachusetts; London, England: The MIT Press. doi:10.2307/j.ctt17kk8bm.8

163 The Reciprocal Relation of Semiotic Architectural Space and Semiotic Filmic Space I Interactive Arch., http://www.interactivearchitecture.org/the-reciprocal-relation-of-semiotic-architectural-space-and-semiotic-filmic-space-2.html

mental itinerary that, finally, makes film the art that is closest to architecture. Just like architecture, cinema creates mental and emotional maps, acting as membrane for a multifold transport.[164]

Auditory spatial awareness is the internal experience of an external environment. A physical space exist in the world, and the experience of that space exists in the listeners consciousness. Distinction between internal and external spaces are tightly linked. Even we are using spatial synthesisers, however, we have only an internal experience. Audio engineering design "virtual space implementations", and external reality is only an arcane algorithm. The experience of concert hall is also internal and the physical acoustics of an enclosed space only means for creating the internal spatiality. The same cases apply to virtual space synthesisers. In one case, a synthesizer simulates or replicates the listening experience at a particular seat of a realisable concert hall. In the other, a synthesizer creates a spatial fantasy as an aesthetic extension of the musical arts. Initially, the distinction between two cases symbolises different concepts, but when taken to its logical conclusion, the distinction disappears: in both cases, someone must select the attributes of spatiality that are musically relevant and desirable. Whether modelling reality or creating a fantasy, the creator of a virtual space is an aural architect. The fact that musical spatiality had been created by physical spaces is just a historical artefact of older technology.[165]

Layers of cultural memory, densities of hybrid histories, and psycho-geographic transport are housed by film's spatial practice of cognition. A vehicle for cultural voyages, cinema offers tracking shots to traveling cultures. Like the city itself, it is a moving inner landscape, a mobile map, a trace of inner differences as well as cross-cultural travel. In conclusion, to adopt this mobile urban viewpoint for both architecture and film (two seemingly static and optical activities) we must transform our sense of these art forms, to join the paths of research on architecture, cinema and sound as well, not optically but auditory and hapticaly, is to corrode oppositions such as immobility-mobility, inside outside, private-public, dwelling-travel. Architecture and sound are permeable spaces. In between housing and motion, these spaces question the very limits of

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164 Ibid.

165 Blesser, B. Spaces Speak, Are You listening? Experiencing aural architecture. By Dr. Barry Blesser & Dr. Linda-Ruth Salter. Cambridge, MA, The MIT Press, 2006

the opposition. They force us to rethink cultural expression itself as a site of interior exterior travel and dwelling an interstitial space.[166]

Actual and Virtual Spaces

“Space ... exists in a social sense only for activity for and by virtue of walking ... or traveling. “ Henri Lefebvre (dissagree! comment)- The Production of Space, Rhythm analysis - space, time and everyday life

Space that starts from nothing, the eternal. Nothing that we change to something with a thought with an idea. Nothing as a possibility of change. The human condition is based on two concepts of space “actuality” and “virtuality”. What surrounds us is a physical reality, shared reality between us, where 90% of an information processed by our brain is a visual information, that means we tend to avoid our other senses, but from the chaos and noise around us we receive an information about space through all our sensorium and considerable amount of information we receive and interpret from external space by auditory perception.

When we think of a spatial region, we automatically picture an area that has a visible boundaries, which restrict movement, namely walls. But if we think of space in terms of hearing, boundaries are often unrelated to walls. An open window couples two visual spaces fusing them into a single space. A high noise level shrinks the area in which the ear can sense, thus aural space is an area where inhabitants can hear sonic events, and in this definition of space is often related to the visual experience.[167]

If we want draw and enter to a virtual aural space, you will find yourself in an unconstrained soundscape, an virtual environment and you get involved with your senses and the immersive body. This technique can be characterised as a sound-body-space effect or brain-body-space effect.

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166 Bruno, Giuliana. “Visual Studies: Four Takes on Spatial Turns.” Journal of the Society of Architectural Historians 65, no. 1 (2006): 23-24. doi:10.2307/25068236.

167 Blesser, B. Aural Architecture, The Survival Value of Hearing, http://www.blesser.net/downloads/RDC%20Article.pdf

Sound arises from dynamic events - a static world never produces sound.[168] Sound transports the external world to our consciousness and aural experience of an environment is critically important to the social and emotional wellbeing of the inhabitants. While vision requires us to first voluntarily focus on the target; vision is easily obscured by intervening objects; vision requires a light source; and vision is not particularly good for sensing fast movements or rapid change. In contrast, sound flows through space, around obstacles and into cervices. Our hearing is always on, even when we sleep - from evolutionary perspective, hearing made a critical important contribution to survival.[169]

The new composite living sound organisms, inspired by NOISE music, aim to heighten our senses and open our ears and minds to the finer details that make up the world and shared reality.

Through an interdisciplinary thinking, connections between aural and architectural in order to achieve architectural space formed through sound, from the forces of the environment, from forces of nature and build architecture sensitive to aural approach.[170]
Multi-sensory Processing

The availability of multiple sensory modalities and their continuous integration are almost universal features in the animal kingdom. Almost all animals have multiple ways of perceiving. What is clearly being established is that sensory modalities can hardly be considered independently, since they affect each other not only for the whole integrated feeling, but down to the perception of each single modality alone (i.e., what we actually see depends also on what we are hearing, and vice versa).[171] Through all our senses we receive information about our environment and also about thyself, each of our sense formulates different dimensions of our picture of reality, there are many events that our senses are unable to process them or transmit the information to

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168 Ibid.

169 Ibid.

170 The Interplay of Music and Architecture: Layering of Sound and Space, Anja Kostanjšak, Morana Pap

171 Varsani, Puja et al., Sensorial Computing, Chapter 15, p. 265-284 by Springer International Publishing AG, part of Spring Nature 2018 - Filimowicz, Michael, and Veronika Tzankova(eds.), New Directions in Third Wave Human-Computer Interaction: Volume 1 - Technologies, Human–Computer Interaction Series, https://doi.org/10.1007/978-3-319-73356-2_15

other sensory centres with better competence to decipher the stimuli so they doesn't provide us a whole image of real event, or at least not yet.

City Sensing

Sensing technology is now helping drive the transport we use, gives us feedback on our physical performance, and directs us toward our destinations. These technologies can be assembled to form technological bubbles which in turn can create sophisticated services in a variety of daily life situations.[172]

Sensorical Computing

We are witnessing a historical transition where technology has become an integral part of almost every aspect of human life experience. Until recently, this dynamic was forecasted and explored with the advent of what was then termed Ubiquitous Computing.[173]

Human Biofeedback

The idea of biofeedback is old. Everybody controls their own behaviour consciously and subconsciously. Also our look into mirror is feedback. But, seen from the new point of view, the notion of feedback is slightly different. Thanks to new electronic devices we can see our body and mind better than by our naked sensory organs.[174]

Humanity is at a special time in its relationship with technology where there is an increasing likelihood of artificially replicating characteristics which we thought were in the realm of the distinctly human.[175]

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172 Augusto J, Callaghan V, Kameas A et al., Intelligent environments: a manifesto. HumCent Comput Inf Sci 3:12. Springer. 2013. www.hcis-journal.com/content/3/1/12.
doi: https://doi.org10.1186/2192-1962-3-12

173 Weiser M, The computer for the 21st century. In: ACM SIGMOBILE Mobile computing
and communications review – Special issue dedicated to Mark Weiser, vol 3, Issue 3, ACM New York, NY, USA, pp 3-11., (1999) doi: https://doi.org/10.1145/329124.329126

174 Faber, Josef, Biofeedback and Brain Activity. Neural Network World 20, (2): 249-260, 2010

175 Dessy, E., Van Puyvelde, M., Mairesse, O. et al. Cognitive Performance Enhancement: Do Biofeedback and Neurofeedback Work?. J Cogn Enhanc 2, 12–42 (2018). https://doi.org/10.1007/s41465-017-0039-y

By involving the biofeedback devices is possible to provide a biofeedback loop to control the environment that the actor is immersed in. This could be done to train an actor in certain situations or to provide an environment suited to targeting specific body or mental states.

The basic means of achieving this training and interaction with environment is by introducing an EEG electrodes and signal reader (and other body wearables if required such as heartbeat or skin resistance devices), i.e. integrated to the usual VR headset. The software can then follow and uncover the EEG pattern of specific signs in reaction to the environment. This reaction pattern is later used to envelope the immersed scene, and further alterations can be introduced when the sign is observe or recorded. In this way, a target state is induced and a biofeedback loop achieved.

An example of this are meditation training systems, some of which are based on buddhist or yogic techniques which have existed for hundreds of years. Meditation states have specific brainwave signatures which are known. These become the target state to be induced with a specific route of immersion to get there. This may be the concentration on particular objects (known as Kasina). The objects and a surrounding environment are constructed in VR where software checks the focus of the individual and attempts to hold their concentration by manipulating the scene. The response in the EEG is watched and further alterations occur. It is not only training that the introduction of an EEG or other body metrics could be used for. Movies can be constructed to change depending on how the watcher is feeling and therefore relating to the material. Within VR, both games and interactive stories can be made in this way which are malleable or self creating, reacting perhaps to how the participant feels.[176]

Technology has been developing nature-inspired artefacts which resemble somehow their human counterparts with specific practical applications. So far these explorations have been mostly isolated, this is only a matter of time. Such developments will provide machines with interface capacities of a higher order, bringing new powerful tools to solve new problems, whilst

[176] Varsani, Puja et al., Sensorial Computing, Chapter 15, p. 265-284 by Springer International Publishing AG, part of Spring Nature 2018 - Filimowicz, Michael, and Veronika Tzankova(eds.), New Directions in Third Wave Human-Computer Interaction: Volume 1 - Technologies, Human–Computer Interaction Series, https://doi.org/10.1007/978-3-319-73356-2_15

raising unexpected scenarios and challenges for our societies. Thus we look at the artificial and human synergies, how interaction with machines is influenced by sense-like interface capabilities – namely *sensorial computing*.[177]

2.2.2 Data Analysis

Data analysis is a process of inspecting, cleansing, transforming and modeling data with the goal of discovering useful information, informing conclusions and supporting decision-making. Data analysis has multiple angles and approaches, encompassing diverse techniques under a variety of names, and is used in different business, science, and social science domains.[178] In architecture, data analysis plays a role in making decisions more scientific and helping architectural systems operate more effectively.

Data mining is a particular data analysis technique that focuses on statistical modelling and knowledge discovery for predictive rather than purely descriptive purposes, while business intelligence covers data analysis that relies heavily on aggregation, focusing mainly on business information. In statistical applications, data analysis can be divided into descriptive statistics, exploratory data analysis (EDA), and confirmatory data analysis (CDA). EDA focuses on discovering new features in the data while CDA focuses on confirming or falsifying existing hypotheses. Predictive analytics focuses on application of statistical models for predictive forecasting or classification, while text analytics applies statistical, linguistic, and structural techniques to extract and classify information from textual sources, a species of unstructured data. All of the above are varieties of data analysis.[179]

The process of data analysis is represented by the following simple equation:
DATA = MODEL + ERROR

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[177] Ibid.

[178] Xia, B. S., & Gong, P. (2015). Review of business intelligence through data analysis. *Benchmarking*, *21*(2), 300-311. doi:10.1108/BIJ-08-2012-0050

[179] Judd, Charles M., Gary H. McClelland, and Carey S. Ryan. *Data analysis : a model comparison approach*. New York Hove: Routledge, 2009.

Data represents the basic scores or observations, usually but not always numerical, that we want to analyse. Model is a more compact description or representation of the data. Data entering the model are usually large and of a form that is hard to communicate to others. The last part of our basic equation is ERROR, which is simply the amount by which the model fails to represent the data accurately.[180]

2.2.2.1 Dimensionality Reduction

For most practical applications, the original input variables are typically preprocessed to transform them into some new space of variables where, it is hoped, the pattern recognition problem will be easier to solve. For instance, in the digit recognition problem, the images of the digits are typically translated and scaled so that each digit is contained within a box of a fixed size. This greatly reduces the variability within each digit class, because the location and scale of all the digits are now the same, which makes it much easier for a subsequent pattern recognition algorithm to distinguish between the different classes.[181]

This pre-processing stage is sometimes also called feature extraction. Important for the consistency of the dynamic environment model for architectural space is that new test data must be pre-processed using the same steps as the training data. Pre-processing might also be performed in order to speed up computation.[182] For example, if the goal is real-time face detection in a high-resolution video stream, the computer must handle huge numbers of pixels per second, and resenting these directly to a complex pattern recognition algorithm may be computationally infeasible. The surround sound data and acquired brain activity EEG data and their real time processing is another example of the very much computationally demanding model. According to Bishop, however, we can achieve very satisfactory results through dimensionality reduction.

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[180] Judd, Charles M., Gary H. McClelland, and Carey S. Ryan. *Data analysis : a model comparison approach*. New York Hove: Routledge, 2009.

[181] Bishop, Christopher M. Pattern Recognition and Machine Learning. New York :Springer, 2006.

[182] Bishop, Christopher M. Pattern Recognition and Machine Learning. New York :Springer, 2006.

Instead, of processing a large arrays of data without any guideline the aim is to find useful features that are fast to compute, and yet that also preserve useful discriminatory information enabling distinguish between responses to the environment. These features are then used as the inputs to the pattern recognition algorithm. For instance, the average value of the image intensity over a rectangular subregion can be evaluated extremely efficiently (Viola and Jones, 2004), and a set of such features can prove very effective in fast face detection. Because the number of such features is smaller than the number of pixels, this kind of pre-processing represents a form of dimensionality reduction. Care must be taken during pre-processing because often information is discarded, and if this information is important to the solution of the problem then the overall accuracy of the system can suffer.[183]

Here are some of the benefits of applying dimensionality reduction to a dataset:

- Space required to store the data is reduced as the number of dimensions comes down
- Less dimensions lead to less computation/training time
- Some algorithms do not perform well when we have a large dimensions. So reducing these dimensions needs to happen for the algorithm to be useful
- It takes care of multicollinearity by removing redundant features. For example, you have two variables – *artificial lighting* and *energy consumption*. These variables are highly correlated as the more artificial light we need in the streets, the more energy consumption we have. Hence, there is no point in storing both as just one of them does what you require
- It helps in visualizing data. As discussed earlier, it is very difficult to visualize data in higher dimensions so reducing our space to 2D or 3D may allow us to plot and observe patterns more clearly

Dimensionality reduction can be done in two different ways:

- By only keeping the most relevant variables from the original dataset (this technique is called feature selection)
- By finding a smaller set of new variables, each being a combination of the input variables, containing basically the same information as the input variables (this technique is called dimensionality reduction)[184]

[183] Bishop, Christopher M. Pattern Recognition and Machine Learning. New York :Springer, 2006.

[184] https://www.analyticsvidhya.com/blog/2018/08/dimensionality-reduction-techniques-python/?#

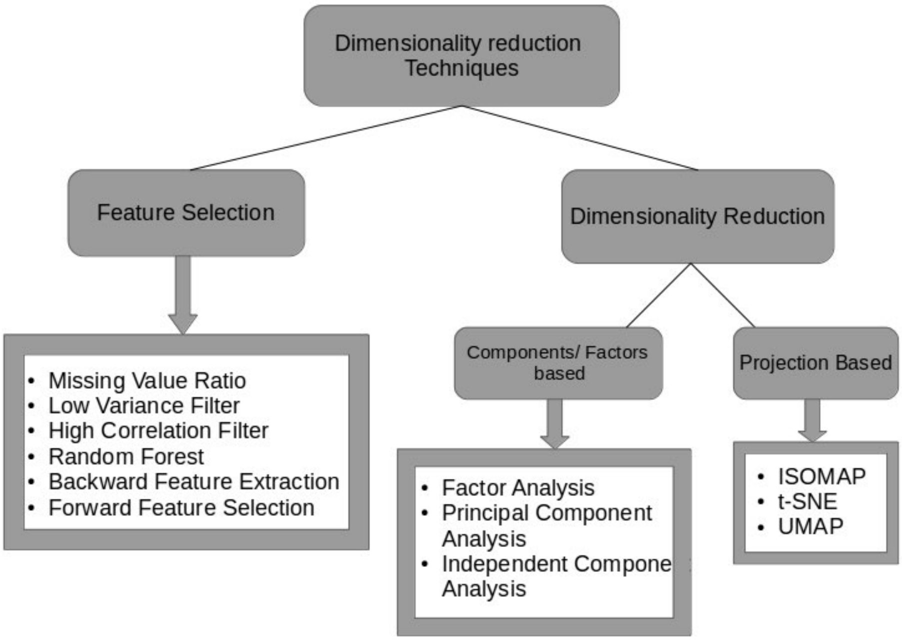

Figure: Dimensionality Reduction Techniques[185]

2.2.2.1 Principal Component Analysis

The prefix Eigen is commonly used in linear algebra, in compounds such as eigenfunction, eigenstate, eigenvector. It comes from the German word eigen which means "one's own, proper." The basic tool for the design of the population of chairs to be investigated in such a way — i.e. *"all the others"* — is the Principal Component Analysis algorithm (Abdi and Williams, 2010). It is a standard tool for contemporary data analysis that has been adapted in various applications according to diverse needs, from neuroscience to computer graphics, and begins now to be applied in the field of design (Sirovich and Kirby, 1987; Turk and Pentland, 1991). Principal Component Analysis reduces a given data set to a set of principal components, i.e. eigenvectors. The key feature of this algorithm is the intersection and interconnection of all data, whose result adapts and changes according to the required point of view, i.e. according to interpretation attributed to the problem.[186]

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185 Ibid.

186 (Applied Virtually Book Series) Ludger Hovestadt & Vera Buhlmann - EigenArchitecture-Ambra Verlag (2013)

By using open-source 3-D models of chairs from the Google warehouse, their geometry is appropriated through a set of algorithms, on which the Principal Component Analysis algorithm is applied to calculate fusions, mergings, and manipulations from the input information, from which new objects can be generated and produced. The result is a population of objects that are over-coding cultural and historical space-time relations through the imposition of logistic networks. The final objects are entirely a product of mathematical and logical thinking, designated according to a particular aesthetic sensibility (mine). The identity of the object is engendered by pure intellect, and contingently rooted in historical and cultural legacies. The main algorithm, which technically organizes the whole project, is the Principal Component Analysis algorithm.[187]

The goals of Principal Component Analysis are :

- to extract the most important informational aspects from the data set,
- to compress the size of the data set by keeping only the important informational aspects,
- to simplify the description of the data set, and
- to analyze the structure of the observations and the variables.

In order to achieve these goals, Principal Component Analysis computes new variables, called principal components or Eigenvectors, which are obtained as linear combinations of the original variables. The first principal component is required to have the largest possible variance. The second component is computed under the constraint of being orthogonal to the first component, and thus needs to have the second largest possible variance. The other components are computed likewise. By changing the values of the principal components, i.e., the eigenweights, we are able to achieve linear transformations between all the objects.

Governed by the Principal Component Analysis algorithm, meta-space is able to correlate indexes of all objects, creating thus an open logistic network, an abstract possibility space.[188]

To the extent that clustering is used for data analysis and comprehension, it is closely related to visualization techniques that project a high-dimensional space onto (usually) two or three

[187] (Applied Virtually Book Series) Ludger Hovestadt & Vera Buhlmann - EigenArchitecture-Ambra Verlag (2013)

[188] Abdi, Hervé and Lynne J. Williams. "Principal Component Analysis." Wiley Interdisciplinary Reviews: Computational Statistics 2, no. 4 (2010): 433–59.

dimensions. Three commonly used techniques are principal component analysis (PCA) (see (Biber et al. 1998) for its application to corpora), Multi-Dimensional Scaling (MDS) (Kruskal 1964a,b) and Kohonen maps or Self-Organizing Maps (SOM) Kohonen 1997).

Principal Component Analysis is a technique which helps us in extracting a new set of variables from an existing large set of variables. These newly extracted variables are called Principal Components.

- A principal component is a linear combination of the original variables
- Principal components are extracted in such a way that the first principal component explains maximum variance in the dataset
- Second principal component tries to explain the remaining variance in the dataset and is uncorrelated to the first principal component
- Third principal component tries to explain the variance which is not explained by the first two principal components and so on[189]

One particular, prototypical algorithm makes self-fictitious things generally applicable: principal component analysis (PCA). Take a cloud of fictitious points of rational talks, and try to make sense of them. PCA helps find that cloud's main, secondary, tertiary, etc. axes of balance. What will these axes do for us?

1. They allow us to establish a new coordinate system
2. one providing maximum contrast
3. which is your private reflection of the world
4. based on such reflections, rational talks are rendered to the world
5. thereby you become a fictitious point of rational talks in the cloud, reflecting all the other fictitious points [190]

The eigenvectors can be understood as the most-balanced dimensionality of a set of data.

Vector, Tensor, Matrix, Cluster

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189 https://www.analyticsvidhya.com/blog/2018/08/dimensionality-reduction-techniques-python/?#

190 (Applied Virtually Book Series) Ludger Hovestadt & Vera Buhlmann - EigenArchitecture-Ambra Verlag (2013)

When it comes to data analysis and machine learning methods concerning spatial data representation, there are basic mathematical elements that we use to define space and behaviour of data in this space.

Vector

A vector is formally defined as an element of a vector space. In the commonly encountered vector space $\mathbb{R}^n$ (i.e., Euclidean n-space), a vector is given by n coordinates and can be specified as $(A_1, A_2, \ldots, A_n)$. Vectors are sometimes referred to by the number of coordinates they have, so a 2-dimensional vector (x_1, x_2) is often called a two-vector, an n-dimensional vector is often called an n-vector, and so on.
Vectors can be added together (vector addition), subtracted (vector subtraction) and multiplied by scalars (scalar multiplication). Vector multiplication is not uniquely defined, but a number of different types of products, such as the dot product, cross product, and tensor direct product can be defined for pairs of vectors.

A vector may also be defined as a set of n numbers A_a, ..., A_n that transform according to the rule

$$A'_i = a_{ij} A_j,$$

where Einstein summation notation has been used,

$$a_{ij} = \frac{\partial x'_i}{\partial x_j}$$

are constants (corresponding to the direction cosines), with partial derivatives taken with respect to the original and transformed coordinate axes, and $i, j = 1$, ..., n (Arfken 1985, p. 10). This makes a vector a tensor of tensor rank one. A vector with n components in called an n-vector, and a scalar may therefore be thought of as a 1-vector (or a 0-tensor rank tensor). Vectors are invariant under translation, and they reverse sign upon inversion. Objects that resemble vectors but do not reverse sign upon inversion are known as pseudovectors. To distinguish vectors from pseudovectors, the former are sometimes called polar vectors.[191]

Tensor

An nth-rank tensor in m-dimensional space is a mathematical object that has n indices and m^n components and obeys certain transformation rules. Each index of a tensor ranges over the number of dimensions of space. However, the dimension of the space is largely irrelevant in most tensor equations (with the notable exception of the contracted Kronecker delta). Tensors are generalizations of scalars (that have no indices), vectors (that have exactly one index), and matrices (that have exactly two indices) to an arbitrary number of indices.

Tensors provide a natural and concise mathematical framework for formulating and solving problems in areas of physics such as elasticity, fluid mechanics, and general relativity.[192]

Matrix

A matrix is a concise and useful way of uniquely representing and working with linear transformations. In particular, every linear transformation can be represented by a matrix, and every matrix corresponds to a unique linear transformation. The matrix, and its close relative the determinant, are extremely important concepts in linear algebra, and were first formulated by Sylvester (1851) and Cayley.

In his 1851 paper, Sylvester wrote, "For this purpose we must commence, not with a square, but with an oblong arrangement of terms consisting, suppose, of m lines and n columns. This will not in itself represent a determinant, but is, as it were, a Matrix out of which we may form various systems of determinants by fixing upon a number p, and selecting at will p lines and p columns, the squares corresponding of pth order."

191 Weisstein, Eric W. "Vector." From *MathWorld*--A Wolfram Web Resource. https://mathworld.wolfram.com/Vector.html

192 Rowland, Todd and Weisstein, Eric W. "Tensor." From *MathWorld*--A Wolfram Web Resource. https://mathworld.wolfram.com/Tensor.html

The word 'Matrix' is already in use to express the very meaning block; or former word means rather the mould, or form, into which algebraical quantities may be introduced, than an actual assemblage of such quantities.[193]

$$x'_m$$

$$=$$

$$a_{m\,1}\,x_1 + a_{m\,2}\,x_2 + \ldots + a_{m\,n}\,x_n$$

is represented as a matrix equation by

$$\begin{bmatrix} x'_1 \\ x'_2 \\ \vdots \\ x'_m \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1\,n} \\ a_{21} & a_{22} & \cdots & a_{2\,n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m\,1} & a_{m\,2} & \cdots & a_{m\,n} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix},$$

where the $a_{i\,j}$ are called matrix elements.

$$\begin{array}{cc} & \xrightarrow{\quad\quad 4 \quad\quad} \\ 3 \Big\downarrow & \begin{bmatrix} a_{1\,1} & a_{1\,2} & a_{1\,3} & a_{1\,4} \\ a_{2\,1} & a_{2\,2} & a_{2\,3} & a_{2\,4} \\ a_{3\,1} & a_{3\,2} & a_{3\,3} & a_{3\,4} \end{bmatrix} \end{array} \qquad 3 \times 4 \text{ matrix}$$

An $m \times n$ matrix consists of m rows and n columns, and the set of $m \times n$ matrices with real coefficients is sometimes denoted $\mathbb{R}^{m \times n}$. To remember which index refers to which direction, identify the indices of the last (i.e., lower right) term, so the indices m, n of the last element a_{34} in the above matrix identify it as an 3×4 matrix.[194]

193

194 Weisstein, Eric W. "Matrix." From *MathWorld*--A Wolfram Web Resource. https://mathworld.wolfram.com/Matrix.html

Cluster

Given a point lattice, a cluster is a group of filled cells which are all connected to their neighbours vertically or horizontally.[195]

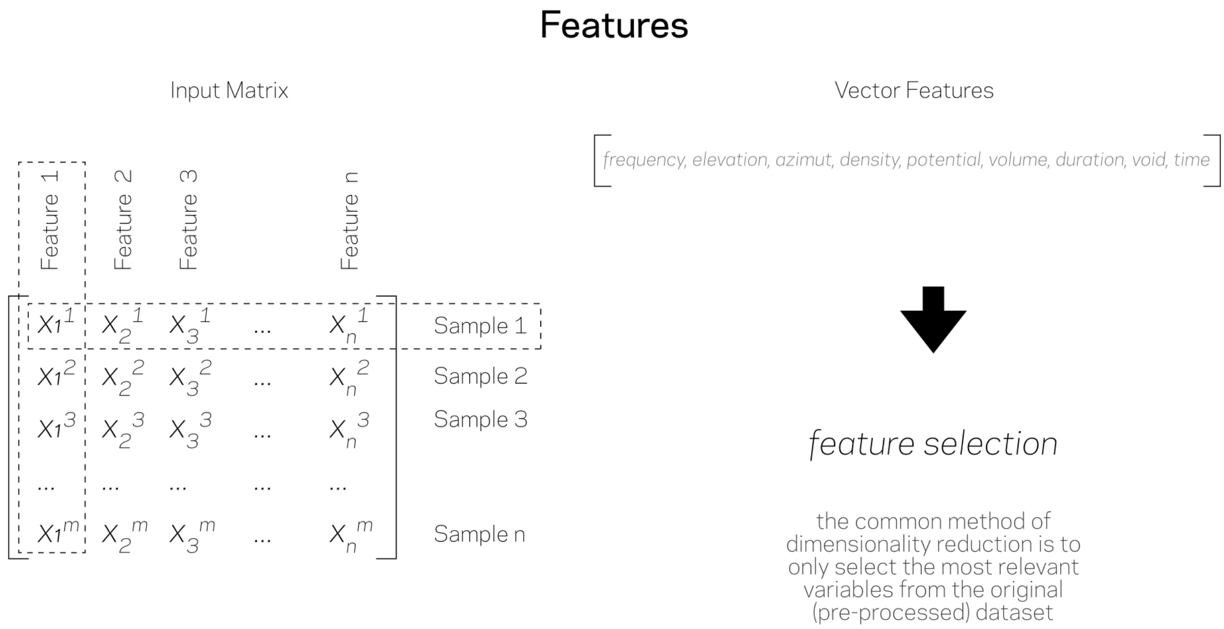


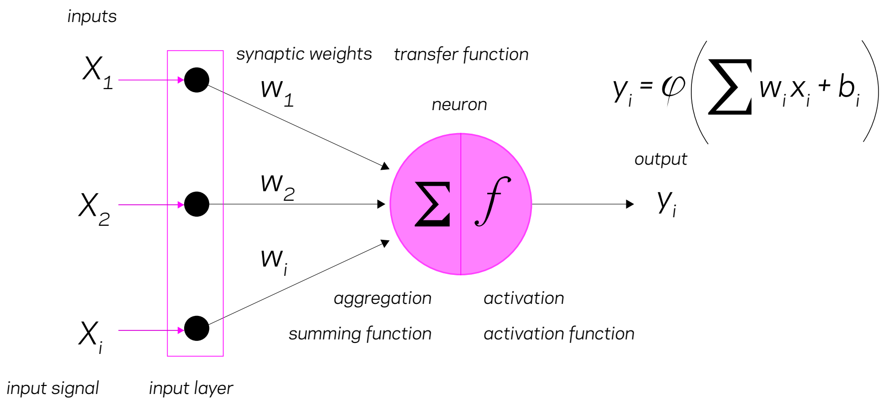
Figure: *Feature Extraction Principle used for the dimensionality reduction in the experimental works by author*

[195] Weisstein, Eric W. "Cluster." From *MathWorld*--A Wolfram Web Resource. https://mathworld.wolfram.com/Cluster.html

2.2.2.3 Machine Perception, Probability Distribution, Pattern Recognition

Any knowledge or strategy of expert systems is based on observing the environment in which they are located, the environment that affects them, which they perceive and learn to interpret it using representational techniques. Based on the ability to determine the properties of this environment, they adopt its characteristics. This is possible thanks to a certain degree of ability of some algorithm of perception, or machine perception.

Machine Perception



Single Artificial Neuron
Perceptron Model (Minsky-Papert in 1969)

Research in machine perception address the hard problems of understanding images, sounds, music and video. In recent years, our computers have become much better at such tasks, enabling a variety of new applications such as: content-based search in Google Photos and Image Search, natural handwriting interfaces for Android, optical character recognition for Google Drive documents, and recommendation systems that understand music and YouTube videos. This approach is driven by algorithms that benefit from processing very large, partially-labeled datasets using parallel computing clusters. A good example is a work on object recognition using a novel deep convolutional neural network known as Inception that allows users to easily search through their large collection of Google Photos. The ability to mine meaningful information from multimedia is broadly applied throughout Google.[196]

[196] https://research.google/research-areas/machine-perception/

Machine perception research that is focused on building a machine that will be endowed with human perceptual ability is following the way of thinking of those narrow minded people of science being preoccupied with topics such as object recognition, object detection or solving the navigation problems. However, as empiricist pointed out, the perception is the source of knowledge acquired through the historically evolved process of collecting of the sensory data, the knowledge that is stored in the form of the scientific books and papers, knowledge that leads to understanding of the world. In this context, it is a truism to say that it is understanding that profits from perception, perception that supplies the nutrition in the form of the sensory data.[197]

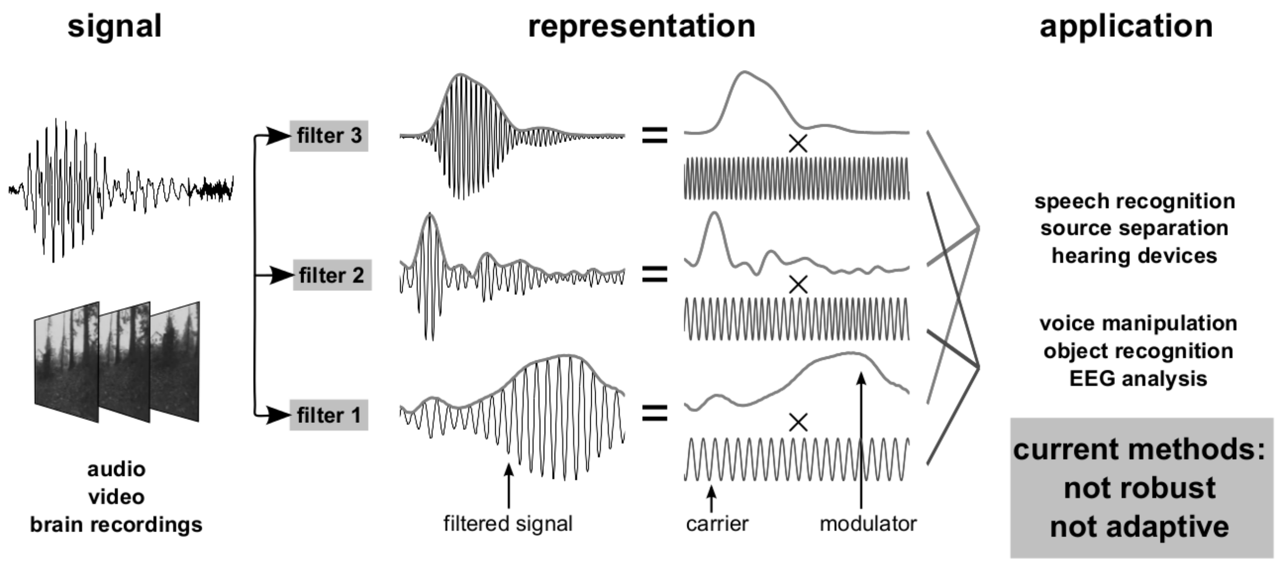


Figure: Signal Representation

There are other research topics that are concerning machine perception problems such as computer vision, machine vision, machine understanding, pattern recognition or robotics, or image understanding in many different domains of our daily life.

Machines that perceive their environments and perform required tasks have an obvious usefulness for diverse application areas safety protocols, industry assembly and inspection, planetary space exploration or automated medical x-ray screening. Or another important application such as Landsat imagery taken from aircrafts or satellites for the monitoring of earth resources, weather patterns, and military surveillance.

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[197] Les, Zbigniew, and Magdalena Les. Machine understanding : machine perception and machine perception MU. Cham, Switzerland: Springer, 2020.

While classical machine perception is focused on gathering sensory information in order to transform it to some form useful to perform required task, machine perception MU, as the part of machine understanding approach, is aimed at building the machine that can think and understand.

Intelligent architectures should have machine learning algorithms so that they can take into account both the dynamics of their environment in which they can easily detect patterns and the properties of this environment, but also a form of machine perception that takes into account the dynamics of the environment shaped by its inhabitants. Intelligent architecture can offer optimal adaptation of the given environment based on its knowledge.

Emotion Recognition[198] and Pattern Recognition

Pattern recognition has its origins in engineering, whereas machine learning grew out of computer science. However, these activities can be viewed as two facets of the same field, and together they have undergone substantial development over the past ten years. In particular, Bayesian methods have grown from a specialist niche to become mainstream, while graphical models have emerged as a general framework for describing and applying probabilistic models.[199]

According to Professor Pelillo, the field of pattern recognition is concerned with the automatic discovery of regularities in data through the use of computer algorithms and with the use of these regularities to take actions such as classifying the data into different categories, with the view to endow artificial systems with the ability to improve their own performance in the light of new external stimuli.[200]

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198 Zhou J, Yu C, Riekki J, Kärkkäinen E (2009) AmE Framework: a Model for Emotion aware Ambient Intelligence. In: Ubiquitous, Autonomic and Trusted Computing (Proceedings of UIC-ATC '09)., pp 428–433

199 Bishop, Christopher M. Pattern recognition and machine learning. New York: Springer, 2006.

200 https://cordis.europa.eu/article/id/30188-extending-the-frontiers-of-artificial-intelligence

The result of running the machine learning algorithm can be expressed as a function y(x) which takes a new digit image x as input and that generates an output vector y, encoded in the same way as the target vectors. The precise form of the function y(x) is determined during the training phase, also known as the learning phase, on the basis of the training data. Once the model is trained it can then determine the identity of new digit images, which are said to comprise a test set. The ability to categorize correctly new examples that differ from those used for training is known as generalization. In practical applications, the variability of the input vectors will be such that the training data can comprise only a tiny fraction of all possible input vectors, and so generalization is a central goal in pattern recognition.[201]

For most practical applications, the original input variables are typically preprocessed to transform them into some new space of variables. This pre-processing stage is sometimes also called feature extraction. These features are then used as the inputs to the pattern recognition algorithm. Applications in which the training data comprises examples of the input vectors along with their corresponding target vectors are known as supervised learning problems.

Probability Theory

A key concept in the field of pattern recognition is that of uncertainty. It arises both through noise on measurements, as well as through the finite size of data sets. Probability theory provides a consistent framework for the quantification and manipulation of uncertainty and forms one of the central foundations for pattern recognition. When combined with decision theory, it allows us to make optimal predictions given all the information available to us, even though that information may be incomplete or ambiguous.[202]

Probability Distribution, Artificial Neural Networks

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[201] Bishop, Christopher M. Pattern recognition and machine learning. New York: Springer, 2006.

[202] Bishop, Christopher M. Pattern recognition and machine learning. New York: Springer, 2006.

Probability distribution is the mathematical function that gives the probabilities of occurrence of different possible outcomes for an experiment.[203] [204]

More specifically, the probability distribution is a mathematical description of a random phenomenon in terms of the probabilities of events.[205]

A probability distribution is a mathematical function that has a sample space as its input, and gives a probability as its output. The sample space is the set of all possible outcomes of a random phenomenon being observed; it may be the set of real numbers or a set of vectors, or it may be a list of non-numerical values.

Probability distributions are generally divided into two classes. A discrete probability distribution (applicable to the scenarios where the set of possible outcomes is discrete, such as a coin toss or a roll of dice) can be encoded by a discrete list of the probabilities of the outcomes, known as a probability mass function. On the other hand, a continuous probability distribution (applicable to the scenarios where the set of possible outcomes can take on values in a continuous range (e.g. real numbers), such as the temperature on a given day) is typically described by probability density functions (with the probability of any individual outcome actually being 0). The normal distribution is a commonly encountered continuous probability distribution. More complex experiments, such as those involving stochastic processes defined in continuous time, may demand the use of more general probability measures.

The event space is discrete and small scale. But dealing with large systems of neurons requires analyzing large numbers of discrete events and also continuous events. To accomplish this purpose requires the notion of a probability distribution.[206]

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[203] Everitt, Brian. (2006). *The Cambridge dictionary of statistics* (3rd ed.). Cambridge, UK: Cambridge University Press. ISBN 978-0-511-24688-3.

[204] Ash, Robert B. (2008). *Basic probability theory* (Dover ed.). Mineola, N.Y.: Dover Publications. pp. 66–69. ISBN 978-0-486-46628-6.

[205] Evans, Michael (Michael John) (2010). *Probability and statistics : the science of uncertainty*. Rosenthal, Jeffrey S. (Jeffrey Seth) (2nd ed.). New York: W.H. Freeman and Co. p. 38. ISBN 978-1-4292-2462-8

[206] Bishop, Christopher M. Pattern recognition and machine learning. New York: Springer, 2006.

Further reading on Data Analysis problematic find at Data analysis: a model comparison approach by Charles M. Judd et.al.[207]

Linear models for Classification

The perceptron algorithm, linear classifier

However, the perceptron convergence theorem states that if there exists an exact solution (in other words, if the training data set is linearly separable), then the perceptron learning algorithm is guaranteed to find an exact solution in a finite number of steps. Proofs of this theorem can be found for example in Rosenblatt (1962), Block (1962), Nilsson (1965), Minsky and Papert (1969), Hertz et al. (1991), and Bishop (1995a). Note, however, that the number of steps required to achieve convergence could still be substantial, and in practice, until convergence is achieved, we will not be able to distinguish between a nonseparable problem and one that is simply slow to converge.

Neural Networks

Artificial neural networks are computational models used in machine learning, computer science, and other research disciplines. They are inspired by and loosely based on biological neural networks. Networks consist of simple elements, which are similar to axons in the brain. ANNs are becoming increasingly popular because they work well for many tasks (e.g. classification or segmentation).

Many neural network models differ in how they work. The essential difference is related to the way feedback is processed. Based on that, we can distinguish two types of ANNs – feedforward networks and feedback networks. Two other interesting and popular types of ANNs are SOM (Self-organizing Map) networks and time delay networks.

[207] Judd, Charles M., Gary H. McClelland, and Carey S. Ryan. *Data analysis : a model comparison approach*. New York Hove: Routledge, 2009.

Feedforward Neural Networks

In general, these are networks in which there are no loops, so there is no feedback. In feedforward networks, signals are transmitted from the input layer through hidden layers (if present) to the output layer. In feedforward networks, signals travel in one direction only; from input to output. Since there is no feedback, the output of any layer does not affect that same layer. The construction of these networks is relatively simple. They are arranged in layers. Each unit only connects with the unit in the next layer. There are no connections within the same layer, connections to previous layers, and connections that skip any of the layers.

Feedback Networks

In feedback networks, the signal can travel in both directions. Sometimes they are called bi-directional networks. In such networks, reverse connections are possible, meaning that the output could be sent to the neurons of previous layers.
Feedback networks are incredibly powerful and can become very complicated. They are also dynamic; their state is constantly changing until the equilibrium point is found. Networks remain in balance until new data is entered, then a new equilibrium point is needed. Feedback networks are often referred to as interactive or recurrent.

Feedback networks are very well suited for recognizing speech or handwriting. For example, in handwriting recognition, performance can increase by knowing the next letters and context of the utterance.[208]

In previous paragraph we considered models for regression and classification that comprised linear combinations of fixed basis functions. We saw that such models have useful analytical and computational properties but that their practical applicability was limited by the curse of dimensionality. In order to apply such models to large-scale problems, it is necessary to adapt the basis functions to the data.

[208] https://www.growly.io/types-of-artificial-neural-networks/

The most successful model of this type in the context of pattern recognition is the feed-forward neural network, also known as the multilayer perceptron. The 'multilayer perceptron' model comprises multiple layers of logistic regression models (with continuous nonlinearities) rather than multiple perceptrons (with discontinuous nonlinearities). The neural networks are efficient models for statistical pattern recognition. In particular, we shall restrict our attention to the specific class of neural networks that have proven to be of greatest practical value, namely the multilayer perceptron.

The number of input and outputs units in a neural network is generally determined by the dimensionality of the data set, whereas the number M of hidden units is a free parameter that can be adjusted to give the best predictive performance. Note that M controls the number of parameters (weights and biases) in the network, and so we might expect that in a maximum likelihood setting there will be an optimum value of M that gives the best generalization performance, corresponding to the optimum balance between under-fitting and over-fitting.

Convolutional networks - CNN

However, there is a class of pattern recognition techniques, in which the training data points, or a subset of them, are kept and used also during the prediction phase. For instance, the Parzen probability density model comprised a linear combination of 'kernel' functions each one centred on one of the training data points.

Probabilities play a central role in modern pattern recognition. Probability theory can be expressed in terms of two simple equations corresponding to the sum rule and the product rule. All of the probabilistic inference and learning manipulations discussed in this book, no matter how complex, amount to repeated application of these two equations. We could therefore proceed to formulate and solve complicated probabilistic models purely by algebraic manipulation. However, we shall find it highly advantageous to augment the analysis using diagrammatic representations of probability distributions, called probabilistic graphical models. These offer several useful properties:

1. They provide a simple way to visualize the structure of a probabilistic model and can be used to design and motivate new models.
2. Insights into the properties of the model, including conditional independence properties, can be obtained by inspection of the graph.
3. Complex computations, required to perform inference and learning in sophisticated models, can be expressed in terms of graphical manipulations, in which underlying mathematical expressions are carried along implicitly.

A graph comprises nodes (also called vertices) connected by links (also known as edges or arcs). In a probabilistic graphical model, each node represents a random variable (or group of random variables), and the links express probabilistic relationships between these variables. The graph then captures the way in which the joint distribution over all of the random variables can be decomposed into a product of factors each depending only on a subset of the variables. We shall begin by discussing Bayesian networks, also known as directed graphical models, in which the links of the graphs have a particular directionality indicated by arrows.

The other major class of graphical models are Markov random fields, also known as undirected graphical models, in which the links do not carry arrows and have no directional significance. Directed graphs are useful for expressing causal relationships between random variables, whereas undirected graphs are better suited to expressing soft constraints between random variables. For the purposes of solving inference problems, it is often convenient to convert both directed and undirected graphs into a different representation called a factor graph.

Recurrent Neural Networks - RNN

Long Short Term Memory networks - LSTM[209]

Auto-encoders

Self-Organising Maps - SOM

Time-Delay Neural Networks - TDNN

Generative Adversarial Networks - GAN

Conditional Adversarial Networks - CAN

Compositional Pattern Producing Networks - CPPN

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[209] https://colah.github.io/posts/2015-08-Understanding-LSTMs/

ShellNet: Point Cloud Convolutional Neural Networks (3DmFV[210] or FoldingNet[211])
For further investigation see The Neural Network ZOO graphs bellow by Jodor Van Veen or at [212] and [213].

2.2.3 Representation Theory

Representation theory is a branch of mathematics that studies abstract algebraic structures by representing their elements as linear transformations of vector spaces,[214] and studies modules over these abstract algebraic structures.[215] [216] In essence, a representation makes an abstract algebraic object more concrete by describing its elements by matrices and its algebraic operations (for example, matrix addition, matrix multiplication). The theory of matrices and linear operators is well-understood, so representations of more abstract objects in terms of familiar linear algebra objects helps glean properties and sometimes simplify calculations on more abstract theories.
The algebraic objects amenable to such a description include groups, associative algebras and Lie algebras. The most prominent of these (and historically the first) is the representation theory of groups, in which elements of a group are represented by invertible matrices in such a way that the group operation is matrix multiplication.[217] [218]

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210 https://github.com/sitzikbs/3DmFV-Net

211 https://github.com/YanWei123/PointNet-encoder-and-FoldingNet-decoder-add-quantization-change-latent-code-size-from-512-to-1024

212 https://www.digitalvidya.com/blog/types-of-neural-networks/

213 https://www.asimovinstitute.org

214 "The Definitive Glossary of Higher Mathematical Jargon — Mathematical Representation". *Math Vault*. 2019-08-01. Retrieved 2019-12-09.

215 Classic texts on representation theory include Curtis & Reiner (1962) and Serre (1977). Other excellent sources are Fulton & Harris (1991) and Goodman & Wallach (1998).

216 "representation theory in nLab". *ncatlab.org*. Retrieved 2019-12-09.

217 For the history of the representation theory of finite groups, see Lam (1998). For algebraic and Lie groups, see Borel (2001).

218 Etingof, Pavel; Golberg, Oleg; Hensel, Sebastian; Liu, Tiankai; Schwendner, Alex; Vaintrob, Dmitry; Yudovina, Elena (January 10, 2011). "Introduction to representation theory" (PDF). *www-math.mit.edu*. Retrieved 2019-12-09.

Representation theory is a useful method because it reduces problems in abstract algebra to problems in linear algebra, a subject that is well understood.[219] Furthermore, the vector space on which a group (for example) is represented can be infinite-dimensional, and by allowing it to be, for instance, a Hilbert space, methods of analysis can be applied to the theory of groups.[220] [221] Representation theory is also important in physics because, for example, it describes how the symmetry group of a physical system affects the solutions of equations describing that system.[222]

Representation theory is pervasive across fields of mathematics for two reasons. First, the applications of representation theory are diverse:[223] in addition to its impact on algebra, representation theory:

- illuminates and generalizes Fourier analysis via harmonic analysis,[224]
- is connected to geometry via invariant theory and the Erlangen program,[225]
- has an impact in number theory via automorphic forms and the Langlands program.[226]

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[219] There are many textbooks on vector spaces and linear algebra. For an advanced treatment, see Kostrikin & Manin (1997).

[220] Sally, Paul; Vogan, David A. (1989), Representation Theory and Harmonic Analysis on Semisimple Lie Groups, American Mathematical Society, ISBN 978-0-8218-1526-7.

[221] Teleman, Constantin (2005). "Representation Theory" (PDF). *math.berkeley.edu*. Retrieved 2019-12-09.

[222] Sternberg, Shlomo (1994), *Group Theory and Physics*, Cambridge University Press, ISBN 978-0-521-55885-3.

[223] Lam, T. Y. (1998), "Representations of finite groups: a hundred years", Notices of the AMS, 45 (3, 4): 361–372 (Part I), 465–474 (Part II).

[224] Folland, Gerald B. (1995), A Course in Abstract Harmonic Analysis, CRC Press, ISBN 978-0-8493-8490-5.

[225] Goodman, Roe; Wallach, Nolan R. (1998), Representations and Invariants of the Classical Groups, Cambridge University Press, ISBN 978-0-521-66348-9.

[226] Borel, Armand; Casselman, W. (1979), *Automorphic Forms, Representations, and L-functions*, American Mathematical Society, ISBN 978-0-8218-1435-2.

Second, there are diverse approaches to representation theory. The same objects can be studied using methods from algebraic geometry, module theory, analytic number theory, differential geometry, operator theory, algebraic combinatorics and topology.[227]

The success of representation theory has led to numerous generalizations. One of the most general is in category theory.[228] The algebraic objects to which representation theory applies can be viewed as particular kinds of categories, and the representations as functors from the object category to the category of vector spaces.[229] This description points to two obvious generalizations: first, the algebraic objects can be replaced by more general categories; second, the target category of vector spaces can be replaced by other well-understood categories.

When representation theory emerged in the late 19th century, many mathematicians questioned its worth. In 1897, the English mathematician William Burnside wrote that he doubted that this unorthodox perspective would yield any new results at all.[230]

Architectural representation

Theory of representation: the study of ways to associate a matrix to each element of the whole.[231]

The architectural representation provides

analytic (numerical)[232]

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[227] Borel, Armand (2001), Essays in the History of Lie Groups and Algebraic Groups, American Mathematical Society, ISBN 978-0-8218-0288-5.

[228] Simson, Daniel; Skowronski, Andrzej; Assem, Ibrahim (2007), Elements of the Representation Theory of Associative Algebras, Cambridge University Press, ISBN 978-0-521-88218-7.

[229] Simson, Daniel; Skowronski, Andrzej; Assem, Ibrahim (2007), Elements of the Representation Theory of Associative Algebras, Cambridge University Press, ISBN 978-0-521-88218-7.

[230] https://www.quantamagazine.org/the-useless-perspective-that-transformed-mathematics-20200609/?fbclid=IwAR0P-rb252j2SQd46cnmaB_IFTgd8b5zhcEPBIjCK344JYpkgKNJ2EgdBZg

[231] Kotnour, K., unpublished notes, 2020

[232] Springer International Publishing AG 2018 M. Hemmerling and L. Cocchiarella (eds.), Informed Architecture, DOI 10.1007/978-3-319-53135-9_2

synthetic (graphical)

outputs.

2.2.4 Information Representation and Knowledge-Based Systems

Data representation strategies

To face the unprecedented complexity of the real world, we must get a deep control and understanding of datasets and, most of all, we have to find new strategies to collect data and process them in order to inform the architecture that is to be formed. Data is a base for development of ambitious strategies and projects, that creates articulated entities, not as a representation of complexity but as the solution for complexity. The recent and still evolving stage of digitalisation applied to architecture demonstrates to us that digital tools are useful to explore a potentially unlimited number of design solutions in order to find the best solution to a specific problem. The design project does not find its essence in a priori defined specific wills but it is the outcome of a process in which an important role is played by new forces that was impossible to describe and control so far. The inspiration and the guidelines of the design intent are no longer collected from the rules of an architectonic tendency or from artistic influences but their reasons are now found in sets of data gathered from the environment. We not only refer to a 1:1 scale built environment but primarily to the realm in which physical forces, structural strain and stresses, or the molecular properties of materials exist and carry out their functions. [233]

Algorithmic design is not simply the use of computers to design architecture and objects. Algorithms allow designers to overcome the limitations of traditional CAD software and 3D modellers, reaching a level of complexity and control which is beyond the human manual ability.[234].

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233 Tedeschi A. and Lombardi D., The Algorithms-Aided Design (AAD) Springer International Publishing AG 2018 M. Hemmerling and L. Cocchiarella (eds.), Informed Architecture, DOI 10.1007/978-3-319-53135-9_4

234 Tedeschi A. and Lombardi D., The Algorithms-Aided Design (AAD) Springer International Publishing AG 2018 M. Hemmerling and L. Cocchiarella (eds.), Informed Architecture, DOI 10.1007/978-3-319-53135-9_4

Probability, entropy and information

Having data measuring an evolving process, the question is how do we measure the information contained in the data? There are several ways to define and to measure information depending on the processes. One way is to use a measure of changes in a process called entropy, calculated with the use of a measure of uncertainties in these changes called probability.

Spatial Representation and Composition Configuration

The dynamic force, are sound signals, our body motion, our behaviour powered by our brain activity. The brain waves represent different states of mind and different emotions and related activities. Neuroscience explains how our brain activity is related to different processes such as unconscious instincts, subconscious emotions, and conscious concentration and mental activity processes, or even extreme focus. The brain performs on slow and fast waves slow waves represents deep brain activity and loss of bodily awareness and fast waves represents mental and creative activity and conscious processes. Brain performance is recognised as a unique sequence of dominate waves that evolve over time. (see Fig.4.1)
Many interrelated evolving complex processes are observed at different levels of brain functionality.[235]

6	evolutionary (population/generation) processes
5	brain cognitive processes
4	system information processing (e.g. neural ensemble)
3	information processing in a cell; cellular (neuron)
2	molecular information processing (genes, proteins)
1	quantum information processing

Data processed by algorithms, and the strategy is suggested and selected, and generate unique architectural structure. The flow the data is processed is shown in the diagram. (See figure 4.2 Data Flow Diagram)

[235] The AUT AI Initiative, http://www.aut.ac.nz/aii

The experience of the sound is unlimited, and we are evaluating the space (perceiving sound) in the 360 degree angles.(see figure 4.3), the signal that we perceive is not, in fact, limited, as it is with light and visual perception throughout our eyes, where the perception is limited by the angle of the field of view, on the surface of the sphere, our retina.(see figure 4.4) or for example of a linear or topographic receptive field, (see figure 4.5).

The proposed approach brings new features that go into architecture.

The prerequisite is the ability to encode the structure as a sound track in architectural form. In this way, we use sounds to manipulate architectural forms. The task is to set up a platform for a selected data representation involving the physical characteristics of sound (external) and brain activity (internal) and to transform their penetrations into structured forms.

Knowledge representation

Knowledge representation has emerged as one of the fundamental topics in the area of computer science known as artificial intelligence (AI). The reason for this is simple: the basic idea is that intelligence, whatever else it involves, does at least involve knowing things, and exploiting them so as to respond appropriately to a given situation. Therefore it seems reasonable to suppose that if we wish to make an intelligent autonomous evolving architectures we must have a way of getting it to know things, and that involves finding a way of representing the things we wish it to know so that they can be encoded within it's own system.

When it comes to write AI programs we find that there are a number of different kinds of things that architects want their algorithm to "know". It will need to know a large number of facts, and to know about the processes which cause those facts to change.

The mean by "representation" is a set of syntactic and semantic conventions that makes it possible to describe things. By syntax we mean that which specifies a set of rules for combining symbols so as to form valid expressions. By semantics we mean the specification of how such expressions are to be interpreted.

The example of knowledge representations with which we are all familiar are maps or.example of various notations used to describe the positions in a game of chess. There are natural languages such as czech or english as the most expressive and powerful knowledge representations available to us.

AI toolkits and Knowledge-based systems

The obvious attractions of combining styles of representation have led to the development of what are called AI toolkits. These toolkits offer an environment, designed to run on a high-performance workstation, for constructing knowledge-based systems: usually the means of building a class hierarchy, and the facility to attach methods to these classes, and some sort of rule system, whether based on a production-rule language or on a logic programming language.

Expert Systems

The use of the term that expert systems have ceased to the more general term knowledge-based systems that has tended to displace it as a term of recommendation for applied AI systems. This means that "expert" systems can be now used to identify a reasonably coherent subset of knowledge-based systems which adhere relatively closely to the original conception. We should not, however, look for a tight definition, but rather a collection of features that we might expect such a system to have.[236]

2.3 Identification of Complex Systems

A complex system is a system composed of many components which may interact with each other. Examples of complex systems are Earth's global climate, organisms, the human brain, infrastructure such as power grid, transportation or communication systems, social and economic organizations, societies, an ecosystem, a living cell, an architecture, and ultimately the entire universe.

[236] Capon, T. J. M. Knowledge representation : an approach to artificial intelligence. London: Academic, 1990.

The term complex systems often refers to the study of complex systems, which is an approach to science that investigates how relationships between a system's parts give rise to its collective behaviors and how the system interacts and forms relationships with its environment.

As a field of study, complex system is a subset of systems theory. General systems theory focuses similarly on the collective behaviors of interacting entities, but it studies a much broader class of systems, including non-complex systems where traditional reductionist approaches may remain viable. Indeed, systems theory seeks to explore and describe all classes of systems, and the invention of categories that are useful to researchers across widely varying fields is one of the systems theory's main objectives.[237] Urban and architectural structures are complex and multidimensional, intertwining natural processes with interactions between large groups of agents, communication flows, information networks, and others. They undergo continuous transformation. The term evolving architecture refers to architecture that relies on physical and virtual processes that transform and assemble into structures in response to environmental properties and capabilities.[238]

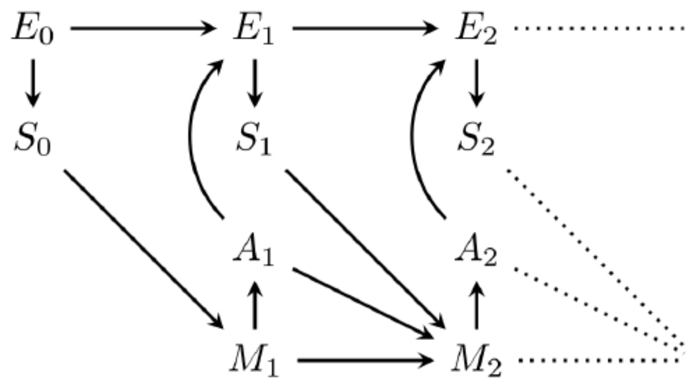

Figure: Deep Reinforcement Learning partially self-observable environment. E -environment, S- state, M- memory, A -action Loop, Perception-action loop diagram

[237] Bar-Yam, Yaneer (2002). "General Features of Complex Systems" (PDF). *Encyclopedia of Life Support Systems*. Retrieved 16 September 2014.

[238] John Frazer, An Evolutionary Architecture (London: Architectural Association Publications, 1995).

A dynamic environment is any space that surrounds us and changes structurally over time, sometimes through modification by groups of agents. Spaces can be closed, with relatively well-defined boundaries, or open, without well-defined boundaries. Examples of confined spaces include homes, offices, hospitals, classrooms, and cars. Open spaces include streets, infrastructure nodes, plazas, parks, fields, air and the sea. The open space environments are usually rich, complex, and unpredictable; they can generate significant "noisy" data, and unstructured and sometimes very dynamic changes. This thesis investigates architecture as a living dynamic system as a complex set of natural and cultural sub-processes in which each interacting entity and system creates complex aggregates. The proposed dynamic models could employ various data, such as from human (transport, communication, information, technology), natural (wind speed, rain, temperature, tornadoes, floods and droughts) and biodiverse (microorganisms, animals,insects, plants) activities. Machine-learning methods make it easier to reveal and use correlations, patterns and transformations. About complex system such as architecture can be deduce very little from single series of numbers, but we learn much more when we can compare between different data series.

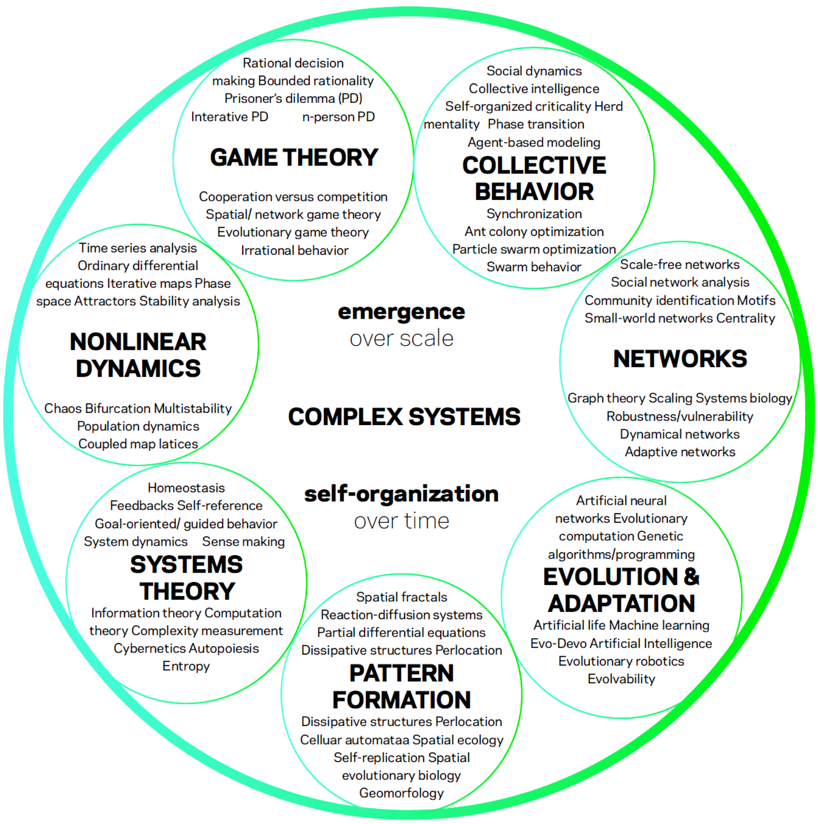

Figure: Complex Systems domains diagram

II. Sound Shape Space

Sound and Light

Sound and light are of a special importance as they, first, affect how we perceive the world, and second, the way we perceive them can be used as inspiration for neural networks architectures and for brain-inspired AI that deal with visual and audio information. Light is important electromagnetic radiation that is characterised by certain frequencies and energy. The speed of light is used as an universal constant. It is 299,792,458 m/s. The primary properties of visible light are: intensity, propagation direction, frequency or wavelength spectrum, polarisation, energy.

Light has the properties of electromagnetic waves characterised by frequencies; and of quantum particles, photons— that is the energy transferred from the light. When white light illuminates an shape or a object, the reflected light at different pixels may have different brightness as the reflected light has different frequencies, different brightness means different frequencies of the wave that reaches our retinas cells.

Sound is an oscillation under pressure, that is spread as waves in a medium.

Space

"Spatial design today means a weaving together of spatial elements, which are mostly achieved in invisible but clearly discernible relationships of multidimensional movement and in fluctuating energy relationships. "

(László Moholy-Nagy)

"*…we can only distinctly conceive distance of space or time up to a certain definite limit; that is, all objects distant from us more than two hundred feet, or whose distance from the place where we are exceeds that which we can distinctly conceive, seem to be an equal distance from us, and all in the same plane; so also objects, whose time of existing is conceived as removed from the present by a longer interval than we can distinctly conceive, seem to be all* *equally distant from the present, and are set down, as it were, to the same moment of time."*[239]

Noise

By definition, any unwanted sound is called "noise." A sound is defined as a vibration, or a traveling wave that is an oscillation of pressure transmitted through a medium (solid, liquid, or gas).

Sound

Whatsoever affects our ears is said to give rise to noise, sound, or harmony.[240] Human auditory system is one of the externally oriented attention, it is a system which orients us to sound. Investigation the architecture of sound and echo shift design practice away from its overemphasis on the visual. In the terms of architectural space there has been little focus on the effects of noise on human behaviour, emotion and creativity. Researchers who study the buildings of ancient cultures suggest that their design may have been generated from predominantly acoustical rather than visual considerations, and these ancient places relied on human social interaction and participation to activate the multisensory space (multisensory experience). Just as leaves comes alive in a wind, so too can the actions of people become design features that enliven architectural space.[241]

Sound Energy

In physics, sound energy is a form of energy that can be heard by humans. Sound is a mechanical wave and as such consists physically in oscillatory elastic compression and in

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239 Spinoza, Benedict, The Ethics (Ethica Ordine Geometrico Demonstrata) translated by R. H. M. Elwes Part IV: Of the Power of the Understanding, or of Human Freedom A Penn State Electronic Classics Series Publication, Copyright © 2000 The Pennsylvania State University

240 Spinoza, Benedict, The Ethics (Ethica Ordine Geometrico Demonstrata) translated by R. H. M. Elwes Part I: Of the Power of the Understanding, or of Human Freedom A Penn State Electronic Classics Series Publication, Copyright © 2000 The Pennsylvania State University

241 Blesser, B. Spaces Speak, Are You listening? Experiencing aural architecture. By Dr. Barry Blesser & Dr. Linda-Ruth Salter. Cambridge, MA, The MIT Press, 2006, 436 pp.

oscillatory displacement of a fluid. Therefore, the medium acts as storage for both potential and kinetic energy.

Space

In mathematics four-dimensional space is referred to as hyperspace and I refer to seeing in hyperspace as hyperseeing. Thus in hyperspace one could hypersee a three-dimensional object completely from one viewpoint.[242]

Energy

Energy is a major characteristic of any object and organism. It is a quantitative entity that they need to do some work, to move, to heat, to stay alive. There are many aspects of energy under this general definition, including quantum, physical, chemical, thermal, biological etc.[243]

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242 Friedman, N.A., Hyperspace, Hyperseeing, Hypersculptures, *Hyperspace*, volume 7, 1998, Japan Institute of Hyperspace Science, Kyoto, Japan. https://ci.nii.ac.jp/naid/40004957432/en/

243 Kasabov N.K., Time-Space, Spiking Neural Networks and Brain-Inspired Artificial Intelligence. Springer Series on Bio- and Neurosystems, vol 7. Springer, Berlin, Heidelberg, (2019) pp.11

3. Natural Computation

The overall perspective of Natural Computation is that learning algorithms develop behavioural programs. Such algorithms can be seen as being driven by the minimum-description-length principle. The brain works to improve its owner's chances of survival by working simultaneously to increase the speed of execution of its programs and the size of its behavioural repertoire.

We define three main types of learning algorithms: neural networks, reinforcement learning, and genetic algorithms. These algorithms operate at very different timescales, but they share a common theme in that they are all optimisation algorithms that try to find good solutions to problems using examples as input. Although these algorithms can be useful in many situations, much leverage is gained by studying them as models of brain computation. Thus developmental learning is developed with the objective of encoding quick reactions to stimuli. Reinforcement learning is developed with respect to the brain's problem of using secondary rewards. Genetic algorithms are developed in the context of searching the space of brain architectures.[244]

3.1 Evolutionary Strategies for Architecture

"Eventually all the universe will be reduced to an uniform, boring jumble: a state of equilibrium, wherein entropy is maximised and nothing meaningful will ever happen again. Living systems harvest energy from their environment to sustain this non-equilibrium state. Life can be considered as a computation that aims to optimise the storage and use of meaningful information."

Robert B. Lisek

The project research a living dynamic system as a complex set of natural and cultural sub-processes where each of the mutually interacting entities and systems create a complex aggregates. It deals with natural processes, communication flows, information networks, resources distributions, dense masses of noise sounds, large group of agents and their spatial interactions in environment. The project proposes a new strategy for creating the evolving architectural structures with spatial sound prints as behavioural patterns and unique intuitive architectural environments. Evolving Architecture employs physical and virtual processes that are transformed and assembled into structures with the respect to the environmental qualities and

[244] Ballard, Dana H. An introduction to natural computation. Cambridge, Mass: MIT Press, 1997.

capabilities, energy transmission and communication flow. Significantly expanding existing research, the project creates a meta-learning model useful for testing various aspects of continuous adaptation of agents in complex dynamic environments. This refers to the difficulty of designing artificial agents that can respond intelligently to evolving complex processes. The model can modulate the overall system transitions and predict its possible long-term outputs e.g.: the fact that important long-term consequences of human activity could follow from events that at first may seem marginal.

The meaningful architecture is impermanent, in the constant process of change and optimised mutations, short and long term adaptations of the successful designs. “The conditions of the term “design” are very different from the norm: when we “design”, we “design”, we are clear in our intentions, but perhaps “blind” to the eventual outcome of the process that we are creating. This blindness can cause concern to those with traditional design values who relish total control. It can alarm those who feel that what we are proposing might get out of control like a computer virus.”[245]

The traditional documentation of architectural production and construction design is replaced by the code of nature in a set of natural computation instructions and formulas which reflect and adapt on a particular multidimensional dynamical environmental and spatial context which they interpret, in architectural representation. With the proposed approach to architectural design goes further beyond the set of architectural plans, and formulate a coded set of responsive instructions, that John Frazer named the “genetic code of architecture”. This approach offers a model of form-generating process based on dynamic environmental changes and intended and directed triggering instructions encapsulated in the whole architectural meta-scripts.

In this research the method of writing of architectural code, and genetic code for architectural adaptation is outlined, intelligent models for spatial adaptation and optimisation in the multidimensional dynamic environment are proposed and and tested in the context of the virtual intelligent environments. The environment is defined by dynamic forces of spatial soundscapes and susceptibility to these audio stimuli in human brain.

[245] Frazer, John. *An evolutionary architecture*. London: Architectural Association, 1995.

This research progress on Evolving Architecture and outlines the new framework for effective continuous architectural response to the dynamic environmental situation, the Evolutionary Meta-learning Models introduce and reviews the principles of Neuro-Evolutionary processes for the successful modification of architectural code, in the Dynamic Environments that is described by the model of and sets of external forces and defines the architectural analysis approach for the multivariable complex dynamic environments. The Spatial Adaptation introduces the criteria for architectural code representation of the algorithms outputs and present evolved architectural models.

Evolving Architecture

The Evolving Architecture engaged with the natural design processes and organisms growth like intelligence, environmentally depended with human like perception i.e. representing sound perception. The contextual (environmentally depended) neuro-evolutionary architectural model as in the natural ecosystems is the code script that continuously evolve and rewrite self. The Evolving Architecture apply the qualities of the natural design processes and consist a dynamic adaptation to the environmental changes of the built environment.

“Charles Darwin established a new world which broke away from the Newtonian paradigm of stability - a world in a continuous process of evolution and change. Modern physics now describes a world of instability. Ilya Prigogine (Nobel laureate noted for his work on dissipative structures, complex systems, and irreversibility.) has discovered new properties of matter in conditions that are for from equilibrium, revealing the prevalence of instability which is expressed by the phenomenon of small changes in initial conditions leading to large amplifications of the effects of the changes.”[246]

The perfection and variety of natural forms is the result of the relentless experimentation of evolution. The analogy of evolving architecture should not be understood just in the matter of the applied natural processes of developing forms through natural selection, but as well in restless

[246] Menges, Achim, and Sean Ahlquist. *Computational design thinking*. Chichester, UK: John Wiley & Sons, pp. 151, 2011.

tendency of optimisation and self-organisation that significantly improve the effectivity and strength of diverse natural prototyping.

The architecture is a designing for survival, designing for life, and emphasised the need for a responsible approach to energy and material transformation and formation. The most of it is coded in natural systems, and processed with powerful biological computational models, the inspiration for this approach to architecture is in general principles of interaction with the environment that are directly applied to the architectural code. The solution to dynamical environmental problems lie in relating architecture to the contextual understanding of the structure of nature.

Negroponte in The Architecture Machine Book[247] suggested, the evolutionary design process, could be presented to a machine, and considered as evolutionary, to give a mutual training resilience and growth. Negroponte placed high expectation first on computer hardware, then on software through artificial intelligence.

Meta-learning

This novel architecture approach is based on meta-learning. Meta-learning goes by many different names: learning to learn, multi-task learning, transfer learning, etc. People easily transfer knowledge acquired in solving one task to another more general task. This means that we naturally recognise and apply previously acquired knowledge to new tasks. The more the new task is related to our previous experience, the easier we can master it. In contrast, popular machine learning algorithms deal with individual tasks and problems. Transfer learning attempts to change this by developing methods to transfer knowledge acquired in one or more source tasks and using them to improve learning in a related target task. The goal of transfer learning is to improve learning in the target task by using knowledge from the source task. When an artificial agent applies knowledge from one task to another, it is helpful to map and embedded the characteristics of one task to the characteristics of another. Techniques enabling knowledge transfer will constitute significant progress in AI and architecture.

[247] Negroponte, Nicholas. *The architecture machine*. Cambridge, Mass: M.I.T. Press, 1970.

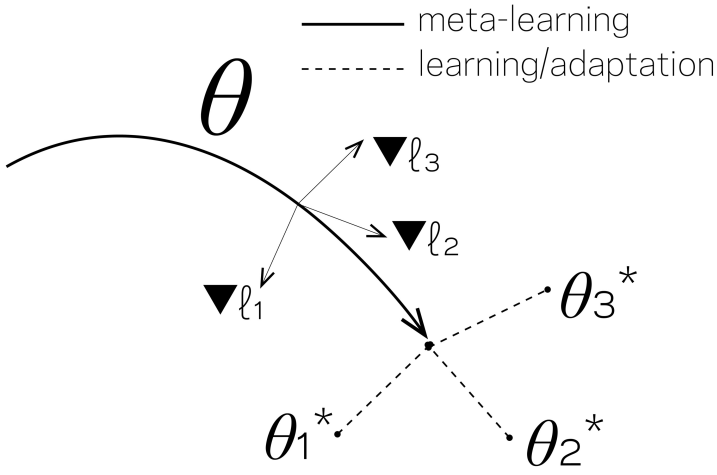

Figure: Meta-Learning diagram with learning and adaptation phase

Modular Implementation

The proposed strategy for learning is of a set of neural network modules that can be combined in different ways. Different modular structures are trained on a set of related tasks and generalise to new tasks by composing the learned architectural modules in new ways. It quickly learn something about a new task based on previous tasks without training the model from scratch. Please see drawing below where system finds appropriate two modules that can be combined as optimal solution for new task.

NeuroEvolution

There are known four different neuro-evolution algorithms. The principle of the algorithm is from the simple weight evolution over a topologically static neural network (CNE), or Covariance Matrix Adaptation Evolutionary Strategy (CMA-ES), to the evolution of weights and topology (NEAT[248]), and indirect encoding of network weights (HyperNEAT[249]). All algorithms encode Artificial Neural Networks (ANNs) which are represented by weights and connectivity (also called topology). The

[248] K. O. Stanley and R. Miikkulainen. Evolving Neural Networks Through Augmenting Topologies. Evo-lutionary Computation , 10(2):99{127, 2002.

[249] J. Gauci and K. O. Stanley. A case study on the critical role of geometric regularity in machine learning. In Proceedings of the 23rd National Conference on Articial Intelligence (AAAI) , 2008.

first two algorithms search over just the weights of the ANN while the latter two have the capacity to also modify the topology.[250]

Meta-HyperNEAT

The proposed evolutionary meta-learning model for Architectural Intelligence, is based on the multiple dynamic aspects, behavioural and environmental forces, defined as algorithms and instance features. The model is build as a system of self-evolved large scale neural networks, HyperNEAT(NeuroEvolution of Augmented Topologies) with multiple input variables based on a meta-learning model methods, Meta-HyperNEAT, that can learn to perform various tasks without having to train on a large data sets.

The model use a set of evolutionary pressures that are employed in the algorithm and initiate the dynamic adaptation to the environmental forces. HyperNEAT[251],[252],[253] evolves an indirect encoding called a Compositional Pattern Producing Network (CPPN). The CPPN is used to define weight of an ANN that produces a solution for the problem. In the proposed model the inputs of CPPN (Convolutional Pattern Producing Network) are employed with a 3-rd dimension and with multidimensional neuro-biofeedback data, where EEG arrays are clustered of evoked response potentials initiated by spatial audio stimuli in an example of this work.

Spatial Evolution and Adaptability

The Evolutionary Meta-Learning Models provide an instinctive adaptability of the neural networks in dynamic environments.

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[250] M. Hausknecht, J. Lehman, R. Miikkulainen and P. Stone, "A Neuroevolution Approach to General Atari Game Playing," in *IEEE Transactions on Computational Intelligence and AI in Games*, vol. 6, no. 4, pp. 355-366, Dec. 2014, doi: 10.1109/TCIAIG.2013.2294713.

[251] J. Gauci and K. O. Stanley. A case study on the critical role of geometric regularity in machine learning. In Proceedings of the 23rd National Conference on Articial Intelligence (AAAI) , 2008.

[252] K. O. Stanley. Compositional pattern producing networks: A novel abstraction of development. Genetic Programming and Evolvable Machines , 8(2):131{162, 2007.

[253] K. O. Stanley, D. B. D'Ambrosio, and J. Gauci. A hypercube-based encoding for evolving large-scale neural networks. Articial Life , 15(2):185{212, 2009.

The prototyping, modelling, testing, evaluation and evolution all use formidable power of the computer, but the initial spark comes from human creativity.[254] The Meta-Learning Model shows it's strengths in a large scale dynamic environment such as soundscape, and it has been used for a suggesting the spatial evolution and adaptation of architectural forms. With the Evolutionary Meta-Learning Models the code of a behavioural and evolving architecture system refers to the hierarchical structure of living systems that was analysed by James Miller on seven levels: cell, organ, organism, group, organisation, society, supranational system, where he applied his general systems behaviour theory. The actors learn on the different levels of hierarchy with various scales and complexity of the environment and spread quickly the learned flow of data based experiences and estimations.

The natural science is used for explanation or illustration, it is essential that the science is correct and that the analogy is valid. But when it is used for inspiration and as a take-off point for thought experiments, it matters less, and misunderstood or even heretical ideas can provide much imaginative stimulus. Architectural Intelligence is as a special kind of problem-solving process. The archetypes of the past do not reflect the changing demands of society, the realities of the construction industry, or the critical need for environmentally responsible buildings. An ecological approach to architecture does not necessarily imply replicating natural ecosystems, but the general principles of interaction with the environment are directly applicable.

The economy of the complexity means to maintain it with the hierarchical manner.

"Modern builders need a classification of architectural factors irrespective of time and country, a classification by essential variation. Some day we shall get a morphology of the art by some architectural Linnaeus or Darwin, who will start from the simple cell and relate to it the most complex structures."[255]

Meta-Architect is a neural network equipped with the ability to combine pre-trained modules in a flexible way to synthesise a new consistent architectural object/task. The software is

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[254] Frazer, John. *An evolutionary architecture*. London: Architectural Association, 1995.

[255] Lethaby, W., 1930. Architecture. An Introduction To The History And Theory Of The Art Of Building. Revised Edition. [2.Impr.]. London: Thornton Butterworth.

autonomous, but the elements, goals and rules of the initial structure are created by the human author. Therefore, meta-composer can be treated as a creative partner and a tool supporting the work of architects and immersive artists.

The natural science is used for explanation or illustration, it is essential that the science is correct and that the analogy is valid. But when it is used for inspiration and as a take-off point for thought experiments, it matters less, and misunderstood or even heretical ideas can provide much imaginative stimulus.

Architectural design as a special kind of problem-solving process. The archetypes of the past do not reflect the changing demands of society, the realities of the construction industry, or the pressing need for environmentally responsible buildings. An ecological approach to architecture does not necessarily imply replicating natural ecosystems,but the general principles of interaction with the environment are directly applicable.

The solution for our environmental problems may lie in relating architecture to the new understanding of the complex structure of nature. The economy of the complexity means to maintain it with the hierarchical manner.

4. Architectural Intelligence

The future is not given – it is under perpetual construction. The future emerges from the interaction of billions of current activities, natural and artificial.[256] The future architecture is capable of perceptual interaction with the environments, and stimulate construction and growth with regard to the needs of natural and artificial aspects of the specific environment.

This isn't a new idea, of course - it's ubiquitous computing, a concept that Mark Weiser introduced in 1991. *"The most profound technologies are those that disappear*," Weiser wrote: *"They weave themselves into the fabric of everyday life until they are distinguishable from it."* [257] We are entering the world of digital technologies and spaces filled with sensors and intelligence that becomes the material of our environments. It becomes our architecture.

To architect means to build a structure and relate detail to it. And when enters the role of humans in those systems, then it is architecture. There are conventionally trained architects who make unconventional approaches to architecture and contribute in the design of complex systems. Whether it is conformable perspective or not, under this definition, we architect. Architecting permit an exploration of the mechanisms behind and within design, and expands the boundaries of practice. It provides the means to model the implications of computation, generativity, and intelligence.

Architecture is ahead of different technological paradigms, such as cybernetics and artificial intelligence, that architects explored at the scale of buildings and the built environment. How do architecting and architecture work when AI is part of the world around us, when algorithms determine so many aspects of our daily lives - our search results, the job postings we see, the movies we might watch, the people we might date? Those who design artificially intelligent systems don't make nouns-objects, buildings, things - they make verbs. They architect machine learning algorithms- the steps that a program will follow to complete a task. They put in place a set of starting conditions, after which the programs program themselves.[258]

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256 Rzevski, G, and Petr Skobelev. *Managing complexity*. Southampton Boston: WIT Press, 2014.

257 Weiser M. The computer for the 21st century. Sci Am. 1991; 265(3):94–104.

258 Steenson, Molly Wright. Architectural Intelligence. MIT Press, 2017.

But where are the architects and designers who design these algorithms into the built architectural environment?

Defining Architectural Intelligence

***Architectural Intelligence** is a set of evolutionary mechanisms that has a capability to adapt the architectural organism to the new environmental situation or behavioural patterns of it's symbionts, in a sort-term or long-term interactions. The **Architectural Intelligence** is both adapting, changing and accommodating the environmental dynamic and behavioural conventions. The architectural intelligence is taught by its architect.*

The intelligence is encoded in a script of a neural networks models that are capable of rewriting existing code protocols, and therefore actively address problematics of architecture for effective and dynamic adaptability. This architectural approach proposes a theory of architectural adaptive systems. Intelligence can be seen as a form of adaptation in which knowledge is constructed by each individual through two complementary processes of assimilation and adaptation.[259] Adaptation is an evolutionary process as a result of which the body better adapts to a dynamically changing environment. If an organism cannot move or change enough to maintain its long-term viability, it will obviously go extinct.

*In this perspective, **Architectural Intelligence** is a set of methods that adapt architecture to the environmental and social changes and instability. **Architectural Intelligence** is a method of solving architectural problems. It assumes to use of computer science techniques, in particular deep learning and meta-learning, to represent and analyse complex architectural and urban phenomena and to find and generate optimal spatial forms. Modelling complex natural processes requires computer science and it is no coincidence that the development of computer science*

[259] Piaget, J. (1952). The Origins of Intelligence in Children. New York, NY: W.W. Norton & Co. https://doi.org/10.1037/11494-000

has been largely shaped by the construction of computer models to simulate natural processes. Based on the developed models, it generate intelligent architectural structures that provide sustainable environmental conditions for individuals and communities based on their spatial experience and behaviour. Predictions generated from models with the use of neural networks actively solve difficult problems of architecture in order to effectively adapt to dynamic changes in the environment.[260]

Figure: Architectural Intelligence as a Complex System Diagram, Karolína Kotnour

[260] Kotnour K., and Lisek R. Evolving Architectures - Spatial Adaptation in Multidimensional Complex Dynamic Environment, 2020

4.1 Artificial Entities

Cognitive Architecture and Computing

Cognitive architectures embody theories of cognition in computer algorithms and programs. As we know, a cognitive architecture is a broadly-scoped, domain-generic computational cognitive model, capturing essential structures and processes of the mind, to be used for a broad, multiple-level, multiple-domain analysis of cognition and behaviour.[261]

The architecture for a building consists of its overall framework and its overall design, as well as roofs, foundations, walls, windows, floors, and so on. Furniture and appliances can be easily rearranged and/or replaced and therefore they are not part of the architecture. With the same key, a cognitive architecture includes overall structures, essential divisions of modules, relations between modules, basic representations, essential algorithms, and a variety of other aspects.[262] In general, architecture includes those aspects of a system that are relatively invariant across time, domains, and individuals. It deals with componential processes of cognition in a structurally and mechanistically well defined way.

Artificial Entities

The function of cognitive computing is to provide an essential framework to facilitate more detailed modelling and understanding of various components and processes of the mind. Research in computational cognitive modelling explores the essence of cognition and various cognitive functionalities through developing detailed, process-based understanding by specifying computational models of mechanisms and processes. It embodies descriptions of cognition in computer algorithms and programs. Detailed simulations are then conducted based on the computational models. In relation to building intelligent systems, a cognitive architecture specifies the underlying infrastructure for intelligent systems, which includes a variety of capabilities, modules, and subsystems. On that basis, application systems can be more easily developed. A

[261] Sun, R. (Ed.). (2005). Cognition and Multi-Agent Interaction: From Cognitive Modeling to Social Simulation. Cambridge: Cambridge University Press. doi:10.1017/CBO9780511610721

[262] Nancy Abraham, Dr & Murugesan, Balamurugan & S, Vijaykumar. (2016). A comparative analysis of cognitive architecture.

cognitive architecture carries also with it's theories of cognition and understanding of intelligence gained from studying the human mind. Therefore, the development of intelligent systems can be more cognitively grounded, which may be advantageous in many circumstances.[263]

For the fields of artificial intelligence and computational intelligence (AI/CI), the importance of cognitive architectures lies in the fact that they support the central goal of AI/CI—building artificial systems that are as capable as human beings.[264] With a cognitive architectures we are capable to reverse engineer intelligent systems in nature, in all levels species, and apply their functional modules to architecture, for example human mind. Human mind constitutes a solid basis for building truly intelligent systems. The use of cognitive architectures in building intelligent systems may also facilitate the interaction between humans and artificially intelligent systems because of the similarity between humans and cognitively based intelligent systems.[265]

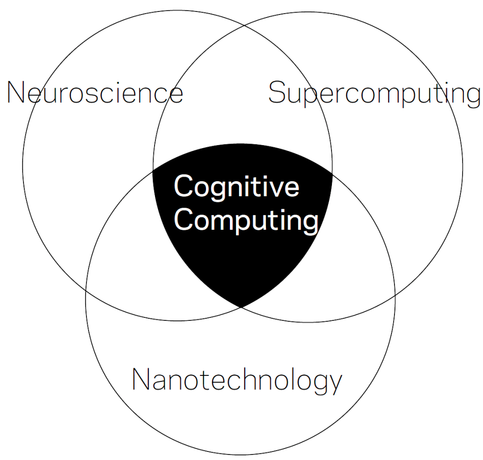

Figure: Cognitive Computing generalization in research fields

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263 Sun, R. (2007). Cognitive Architectures and the Challenge of Cognitive Social Simulation. In: Zhong, N., Liu, J., Yao, Y., Wu, J., Lu, S., Li, K. (eds) Web Intelligence Meets Brain Informatics. WImBI 2006. Lecture Notes in Computer Science(), vol 4845. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-77028-2_10

264 Ron Sun (2007) The importance of cognitive architectures: an analysis based on CLARION, Journal of Experimental & Theoretical Artificial Intelligence, 19:2, 159-193, DOI: 10.1080/09528130701191560

265 Sun, R. (2007). Cognitive Architectures and the Challenge of Cognitive Social Simulation. In: Zhong, N., Liu, J., Yao, Y., Wu, J., Lu, S., Li, K. (eds) Web Intelligence Meets Brain Informatics. WImBI 2006. Lecture Notes in Computer Science(), vol 4845. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-77028-2_10

4.2 Architectural Strategies and Algorithms

After early enthusiasm for the high-performance shape manipulation and rendering offered by digital means, architects started deepening the relationships between architecture and information technology even more. Among the leading examples in Europe, the work of Ludger Hovestadt' s research group at the ETH of Zurich could be mentioned. In charge of the CAAD chair since 2000, he drove research on a new track, inspired by the motto " our credo was not virtual reality, but back to reality". The result was a very rich series of analyses and design experiments carried out on various scales and aspects of architectural project and construction.

This is the area in which the Algorithm-Aided Design (AAD) explores new fields gaining its power from the ability to describe the complexity of the real world through numbers and mathematical functions. The AAD is funded on the analysis of the factors that affect the project itself and, when translated into data, it analyses and uses them in order to inform the process and to optimise the outcome according to a determined fitness function. The AAD has the strength to contain information that would be impossible to control and use through the classical graphic representation. The AAD has the strength to contain information that would be impossible to control and use through the classical graphic representation.

Algorithm in mathematic and computer science, an algorithm is a finite sequence of well-defined, computer-implementable instructions, typically to solve a close of problems or to perform a computation. Algorithms are always unambiguous and are used as specifications for performing calculations, data processing, automated reasoning, and other tasks.[266]

Deterministic algorithm, in computer science, is an algorithm which, given a particular input, will always produce the same output, with the underlying machine always passing through the same sequence of states.Deterministic algorithm computes a mathematical function, that has unique value for any input in its domain, and the algorithm process it in the unique value as output.

[266] https://artsandculture.google.com/entity/algorithm/m0jpv?hl=en

Non-deterministic algorithm, in computer science, is an algorithm that, even for the same input, can exhibit different behaviours on different runs, as opposed to a deterministic algorithm. There are several ways an algorithm may behave differently from run to run.[267]

Probabilistic algorithm's behaviours depends on a random number generator.

In the search of an algorithms for an universal architectural strategies it needs to be considered multilayered character of the dynamic environment. It's behavioural aspects should be observed and integrated in the models and so the evolution of the inputs coming from the environment in to the intelligent architectural entity, algorithm.

Global Optimisation algorithms are imitating certain principles of nature, and phenomenas that can be found in annealing processes, central nervous systems and biological evolution, which lead to the following optimisation methods: Simulated Annealing (SA), Artificial Neural Networks (ANNs) and the field of Evolutionary Computation (EC).

Evolutionary Computing (EC) is only a small part of a scientific field that is sometimes referred to as Computational Intelligence (CI); that in turn is only part of an even more advanced scientific universe concerning Artificial Life, Fractal Geometry, and other Complex Systems Sciences that are referred to as Natural Computation (NC) and a Artificial General Intelligence (AGI).

EC are covering the strategies such as: Genetic Algorithms (GA), Evolutionary programming (EP), Evolution Strategies (ES), Classifier Systems (CFS), Genetic Programming (GP), and several other problem solving strategies. These strategies are based on biological observations, the means of natural selection and the survival of the fittest, and theories of evolution, back from 19th century. The inspired algorithm are thus termed Evolutionary Algorithms (EA) or Evolutionary Strategies for Architecture, simply Architectural Strategies.

Evolutionary Algorithms (EA)is a term used to describe computer-based problem solving systems which use computational models of some of the known mechanisms of evolution as key elements in their design and implementation. They all star a common conceptual base of simulating the evolution of individual structures by processes of selection, mutation, and

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[267] Cormen, Thomas H. (2009). Introduction to Algorithms (3rd ed.). MIT Press. ISBN 978-0-262-03384-8.

reproduction. The processes depend on the perceived performance of the individual structures as defined by an environment.[268]

EA Algorithm example

There are various combinations of circulation GAs, varying in implementation but in essence the algorithms all follow a standard procedure:

1. *Start with a randomly generated population of n l-bit strings (candidate solutions to a problem)*

2. *Calculate the fitness f(x) of each string in the population.*

3. *Repeat the following steps until n new strings have been created:*

- Select a pair of parents strings from the current population, the probability of selection being an increasing function of fitness. Selection is done "with replacement" meaning that the sae string can be selected more than once to become a parent.

- With the crossover probability, cross over the pair at a randomly chosen point to form two new strings. If no crossover takes place, form two new strings that are exact copies of their respective parents.

-Mutate the new strings at each locus with the mutation provability, and place the resulting strings in the new population.

4. Replace the current population with the new population.

5. Go to step 2.[269] [270]

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[268] "An Overview of Evolutionary Computation" [ECML93], 442-459.

[269] Anon. How Do Genetic Algorithms Work?

[270] Shen, Jianjun. Genetic algorithms and genetic programming. GA-GP-text.pdf, University Bielefeld, Germany. 2000. 14 p.

III. Model

B-MAIA - Brain-Machine Artificial Intelligence Architecture

The base for the very early research model framework draws from the concept of Nikola Kasabov and his book Evolving Spiking Neural Networks and Neurogenetic Systems for Spatio- and Spectro- Temporal Data Modelling and Pattern Recognition.[271]

Regarding Kasabov BI-AI systems[272] have six distinctive features:
1. They have their structures and functionality inspired by the human brain; they consist of spatially located neurons that create connections between them through deep learning in time-space by exchanging information—spikes.
2. Being brain-inspired, BI-AI systems can achieve not only deep learning, but deep knowledge representation as well. They are transparent.
3. They can manifest cognitive behaviour.
4. They can be used for knowledge transfer between humans and machines as a foundation for the creation of symbiosis between humans and machines, ultimately leading to the integration of human intelligence and artificial intelligence
5. BI-AI systems are universal data learning machines, being superior than traditional machine learning techniques when dealing with time-space data.
6. BI-AI systems can help understand-, protect-, and cure the human brain.

In the context of human machine symbiosis Kasabov defines a twenty structural, functional and cognitive features of BI-AI systems[273]

Structural Features:

1. The structure and organisation of a system follows the structure and organisation of the human brain, for example through using a 3D brain template.

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[271] Kasabov N. (2012) Evolving Spiking Neural Networks and Neurogenetic Systems for Spatio- and Spectro-Temporal Data Modelling and Pattern Recognition. In: Liu J., Alippi C., Bouchon-Meunier B., Greenwood G.W., Abbass H.A. (eds) Advances in Computational Intelligence. WCCI 2012. Lecture Notes in Computer Science, vol 7311. Springer, Berlin, Heidelberg

[272] Ibid.

[273] Ibid.

2. Input data and information is encoded and processed in the system as spikes over time.
3. A system is built of spiking neurons and connections.
4. A system is scalable, from hundreds to billions of neurons and trillions of connections.
5. Inputs are mapped spatially into the 3D system structure.
6. Output information is also presented as spike sequences.

Functional Features

7. A system operates in a highly parallel mode, potentially all neurons operating in parallel.
8. A system can be implemented on various computer platforms, but more efficiently on neuromorphic highly parallel platforms and on quantum computers (if available).
9. Self-organised unsupervised, supervised and semi-supervised deep learning is performed using brain-inspired spike-time learning rules.
10. The learned spatio-temporal patterns represent deep knowledge.
11. A system operates in a fast, incremental and predictive learning mode.
12. Different time scales of operation, e.g. nanoseconds, milliseconds, minutes, hours, days, millions of years (e.g. genetics), can be represented, possibly. in their integration
13. A system can process multimodal data from all levels of functionality (e.g. quantum; genetic;neuronal; ensembles of neurons; etc.), possibly in their integration.

Cognitive features

14. A system can communicate with humans in a natural language.
15. A system can make abstractions and discover new knowledge (e.g. rules) through self-observing its structure and functions.
16. A system can process all kinds of sensory information that is processed by the human brain, including: visual-, auditory-, sensory-, olfactory-, gustatory, if necessary in their integration.
17. A system can manifest both sub-conscious and conscious processing of stimuli.
18. A system can recognise and express emotions and consciousness.
19. Deep knowledge can be transferred between humans and machines using brain signals and other relevant information, e.g. visual, etc.

20. BI-AI systems can form societies and communicate between each other and with humans achieving a constructive symbiosis between humans and machines.[274]

Some of the very first models of the spatial emotion recognition were based on the medical research and theoretical work of Hugo Lövheim and his concept of Cube of Emotion.[275] Lately there was made an another research by Jordi Vallverdu in collaboration of Hugo Lövheim and his goup presented at The 9th Annual International Conference on Biologically Inspired Cognitive Architectures, the Ninth Annual Meeting of BICA Society in Prague.[276] Or recently extended idea of Cube of Emotion in the Neuropunk Revolution research.[277]

Cube of Emotions

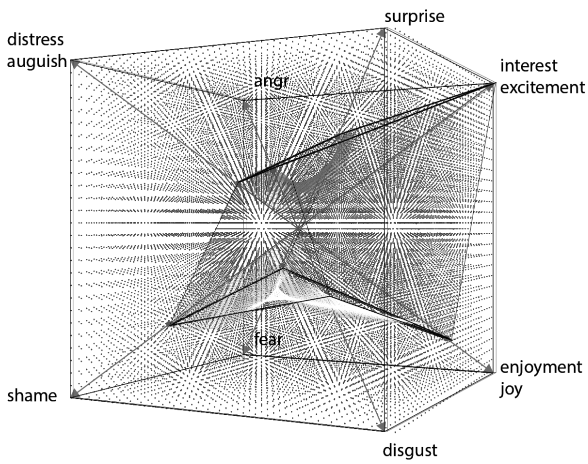

Figure: Cube of Emotion, Matrix of emotion distribution, diagram by author based on Hugo Lövheim conceptual theoretical research, Karolína Kotnour

To draw a relationship between sound signal our perceiving and its representation I borrowed a theoretical model a cube of emotion as an concept of a spatial representation of human body and emotion in space. The centre point of a cube of emotion is kind of a state of nothing, equilibrium, the moment we feel all the emotion at once, absolute consciousness, ecstatic state,

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[274] Kasabov, Nikola. (2018). Deep Learning in Spiking Neural Networks for Brain-Inspired Artificial Intelligence. CompSysTech'18: Proceedings of the 19th International Conference on Computer Systems and Technologies. 1-1. 10.1145/3274005.3274006.

[275] Lövheim, H. (2012). A new three-dimensional model for emotions and monoamine neurotransmitters. Medical Hypotheses, 78(2), 341-348. DOI: 10.1016/j.mehy.2011.11.016

[276] Talanov, Max & Leukhin, Alexey & Lövheim, Hugo & Vallverdu, Jordi & Toschev, Alexander & Gafarov, Fail. (2019). Modeling Psycho-Emotional States via Neurosimulation of Monoamine Neurotransmitters. 10.1007/978-3-030-03104-6_6.

[277] Talanov, Max & Vallverdu, Jordi & Adamatzky, Andrew & Toschev, Alexander & Suleimanova, Alina & Leukhin, Alexey & Posdeeva, Ann & Mikhailova, Yulia & Rodionova, Alice & Mikhaylov, Alexey & Serb, Alexander & Shchanikov, Sergey & Gerasimova, S.A. & Dehshibi, Mohammad Mahdi & Hramov, Alexander & Kazantsev, Victor & Tsoy, Tatyana & Magid, Evgeni & Lavrov, Igor & Warwick, Kevin. (2022). Neuropunk Revolution. Hacking Cognitive Systems towards Cyborgs 3.0.

maybe we can say it is a representation of a point of life but static. /this place or this moment/ And by analysing data from our brain activity we put each emotion to the 3D model so they represent the relation in-between emotion.

And here is the moment when architecture comes in, because for an effective distribution of a particles -a matter - a material we have to look at biological systems in many examples, nature geometry operates with minimal and maximal surfaces with an intension of efficient transmission of an energy, and thats the intension, to allow energy to flow efficiently. Effectivity of a matter distribution and the geometry is natural strategy of an energy transmission - architecture of a nature. Material composition and decomposition.

Theory of minimal surface - least surface possible containing a given volume, and the opposite maximal surfaces - maximal surface possible containing a given volume. Finally we have a conceptual model of a brain activity performance in a spatial representation. So every emotion or state of mind can be displayed in a form and in a real time.

Complex Dynamic Environment Models

More contextual shape and consistency of the whole model was finally achieved through studying architectural environment and behaviours as a complex system and dynamic environments.

Dynamic environments

Urban and architectural structures are complex multi-dimensional structures in which natural processes and interactions of large groups of agents, communication flows, information networks, and others are intertwined. The above structures undergo continuous transformations. A dynamic environment is any space that surrounds us and the structure of which changes over time or is modified by groups of agents. There are closed spaces with relatively well-defined boundaries and others that do not have well-defined boundaries, which we can call open spaces. Examples of confined spaces include homes, offices, hospitals, classrooms, and cars. Examples of open spaces are: streets, bridges and parking lots, fields (in agriculture), air (in the case of airplanes) and the sea (for underwater pollution measurements and tsunami early warning system). These environments are usually rich, complex, unpredictable, and can generate significant "noisy" data, unstructured and sometimes very dynamic changes.

Environmental modelling

One of the task of this work was to establish and model an environment which could simulate and, more importantly, influence the performance of the evolving model.

Intelligent Environment

An Intelligent Environment is one in which the actions of numerous networked controllers (controlling different aspects of an environment) is orchestrated by self-programming pre-emptive processes (e.g., intelligent software agents) in such a way as to create an interactive holistic functionality that enhances occupants experiences.[278]

For centuries humans have witnessed scientific and technological leaps that changed the lives of their generation, and those to come, forever. We are no exception. In fact many of those advances are occurring now, in a more or less unpercievable able way. Slowly and silently the technology is becoming interwoven in our lives in the form of a variety of devices which are starting to be used by people of all ages and as part of their daily routine.[279] As predicted by M. Weiser[280], this technology is gradually disappearing from our cognitive front, as we increasingly take for granted its existence.The emergence of a new paradigm requires the convergence of various domains of human activity, many of which are not technological.[281] An intelligent Environment has to have a proactive attitude, it continuously reasoning on how to help the users of that environment, how the . Identifying correctly when help is needed can be extremely difficult in many situations and heavily depends on the information that is available through the sensors, and the knowledge it has about the user. Knowledge about the related world is also very important to understand what the effects of the system can be on that world and what is realistically feasible to achieve on behalf of the user.[282]

Experiment Model

- please see diagram of the proposed model by author, on the 160 page.

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[278] Augusto, J.C., Callaghan, V., Cook, D. *et al.* "Intelligent Environments: a manifesto". *Hum. Cent. Comput. Inf. Sci.* **3,** 12 (2013). https://doi.org/10.1186/2192-1962-3-12

[279] Augusto, J.C., Callaghan, V., Cook, D. *et al.* "Intelligent Environments: a manifesto". *Hum. Cent. Comput. Inf. Sci.* **3,** 12 (2013). https://doi.org/10.1186/2192-1962-3-12

[280] Weiser M, The computer for the 21st century. In: ACM SIGMOBILE Mobile computing and communications review – Special issue dedicated to Mark Weiser, vol 3, Issue 3, ACM New York, NY, USA, pp 3–11., (1999) doi: https://doi.org/10.1145/329124.329126

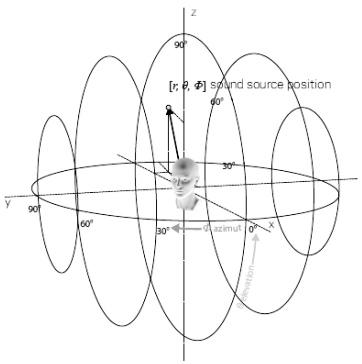
[281] Augusto, J.C., Callaghan, V., Cook, D. *et al.* "Intelligent Environments: a manifesto". *Hum. Cent. Comput. Inf. Sci.* **3,** 12 (2013). https://doi.org/10.1186/2192-1962-3-12

[282] Augusto, J.C., Callaghan, V., Cook, D. *et al.* "Intelligent Environments: a manifesto". *Hum. Cent. Comput. Inf. Sci.* **3,** 12 (2013). https://doi.org/10.1186/2192-1962-3-12

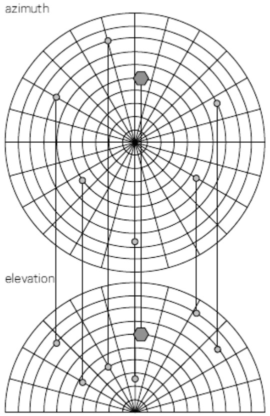
Soundscape

ambisonic sphere - spherical coordinates

r - radius
θ - elevation
Φ - azimut



Sound source position



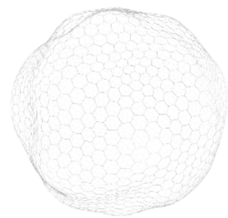
Referebce sound field sphere

The Surrey Sound Sphere (pictured) is used for advanced sound field rendering and perceptual experiments. Such technology could be adopted in open plan living spaces, where multiple occupants consuming audio content would not have to wear headphones. The sphere has allowed different design approaches to be implemented, measured, and evaluated by panels of listeners. The sphere has also been used for perceptual experiments around human localisation of sound sources.
(The Engineering and Physical Sciences Research Council (EPSRC))

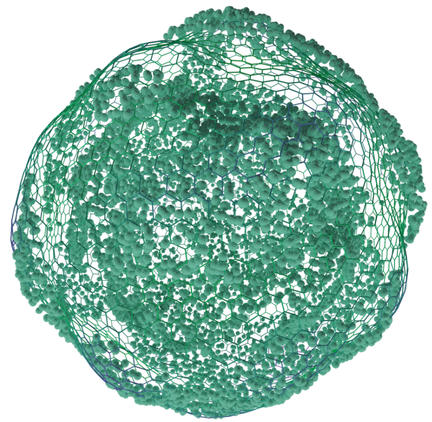
VR soundscape controled by PureData

Ambisonic Sound Sphere Field in VR created with Ambisonic Tools for Pure Data provides a controled dynamic sound environment generated and observed by machine learning algorithm

Sound Spetrogram Field

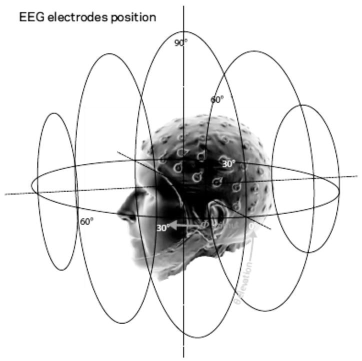


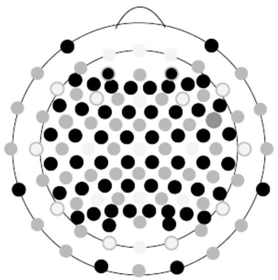
Sound Sphere Stimuli Spectrogram controled dynamic environment model observed by machine learning algorithm



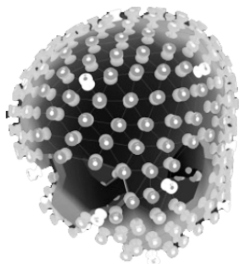
Interpreter - Brain Dynamical Response

EEG electrodes position



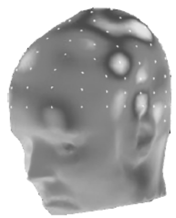


Full 10-5-system. Additional electrode positions in the 10-5 system are indicated by white circles. Standard and extended electrode arrays are indicated (black electrodes: 10-20 system; gray electrodes: 10-10 system; with permission from Oostenveld and Praamstra (2001)).



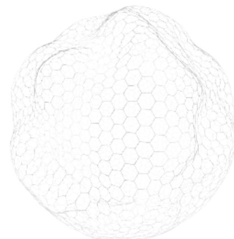
256 electrodes projected onto a 3D healthy human brain. Note the improved spatial sampling from most of the cortical areas (by Laurent Spinelli, University Hospital of Geneva) High-density scalp EEG arrays (64–256 electrodes) allow source imaging with even sub-lobar precision. .

Response Topographical Map



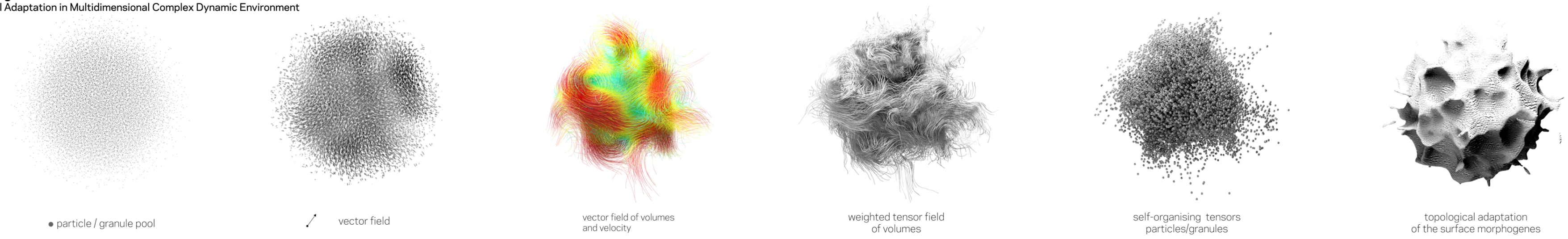
ERP 300 - Evoked Response Potential Dynamic Field 3D topographical scalp maps of brain wave band power

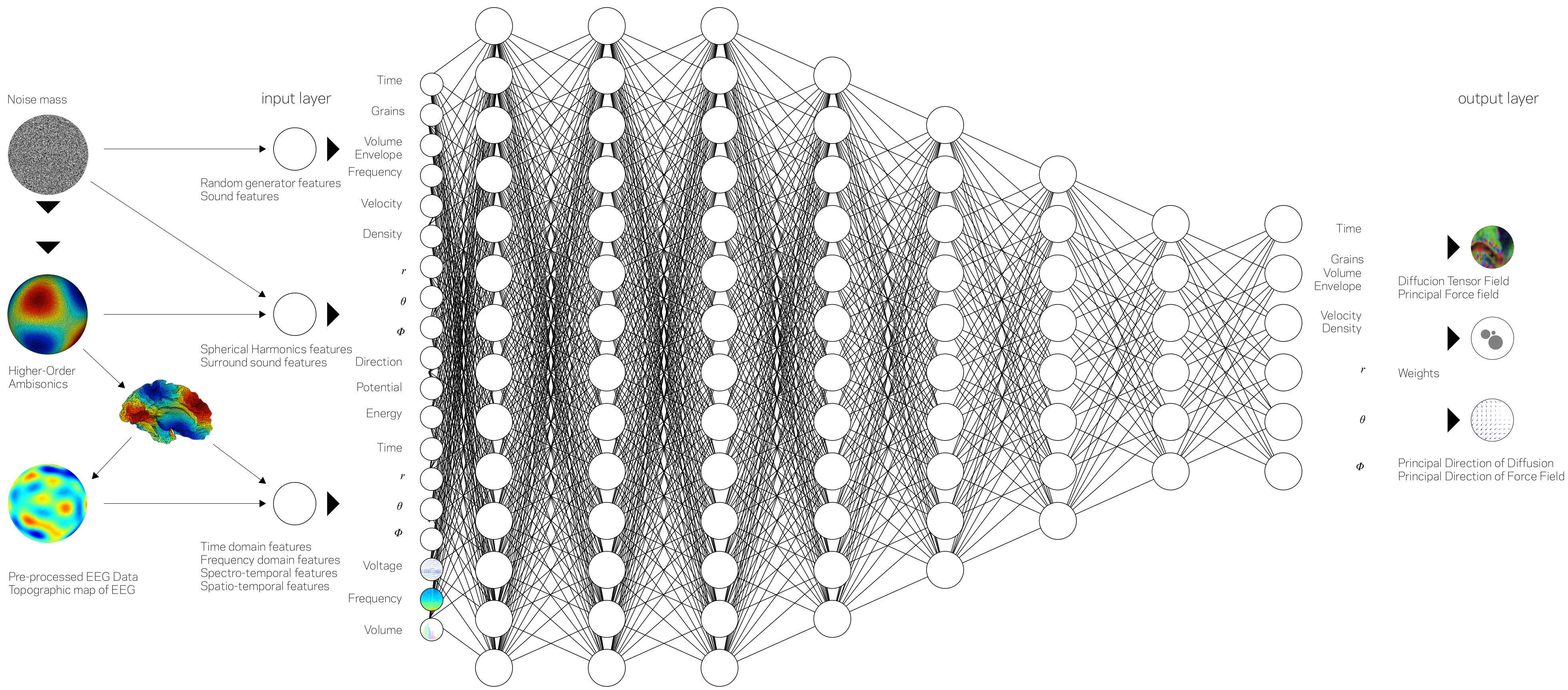
Interpreter Responce Dynamic Field



Topological map of EEG ERP 300 mapped on reference space of controled dynamic environment model observed by machine learning algorithm

Evolving Architecture
Spatial Adaptation in Multidimensional Complex Dynamic Environment





Noise mass
input layer
Random generator features
Sound features
Higher-Order
Ambisonics
Spherical Harmonics features
Surround sound features
Pre-processed EEG Data
Topographic map of EEG
Time domain features
Frequency domain features
Spectro-temporal features
Spatio-temporal features
Time
Grains
Volume
Envelope
Frequency
Velocity
Density
r
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Direction
Potential
Energy
Time
r
θ
Φ
Voltage
Frequency
Volume
Time
Grains
Volume
Envelope
Velocity
Density
r
θ
Φ
output layer
Diffucion Tensor Field
Principal Force field
Weights
Principal Direction of Diffusion
Principal Direction of Force Field

Figure previous page: Machine learning model, feature extraction, dimensionality reduction and super-parameter search diagram, Karolína Kotnour

In the experiment, was found certain relationship between sound and space, respectively an image of this space that the brain creates based on the perception of this sound. I consulted with the IIM (Institute of Intermedia, FEE CVUT) with Michal Rataj (HAMU) Ambisonie, and Zdeněk Otřenášek (MARC - Music Acoustic Research Center) measuring EEG with EmotivEPOC, and psychoacoustics. Based on several consultations, we came to the conclusion of simulating everything in VR, including the "soundscape" sound experience, when in a virtual 3D environment, a sound environment is created, and this environment simulates the spatiality of sound into headphones. However, this leads to problems, the VR headset and the device (Emotiv EPOC) for measuring and recording EEG we no longer get on the volunteer's head. NeuroCap with the professional support of NUDZ (Iveta Fajnerová) and COGSYS CIIRC (Lenka Lhotská) was used for the implementation of the experiment and EEG measurements. The output of this experiment is two types of data streams: a) data stream with information about the position of the sound source and its characteristics (sound stimulation) Ambisonics PureData and SuperCollider b) dataset with recording from EEG (ie recording how sound affected a person at a given moment, resp. adapts more effectively to dynamic conditions.

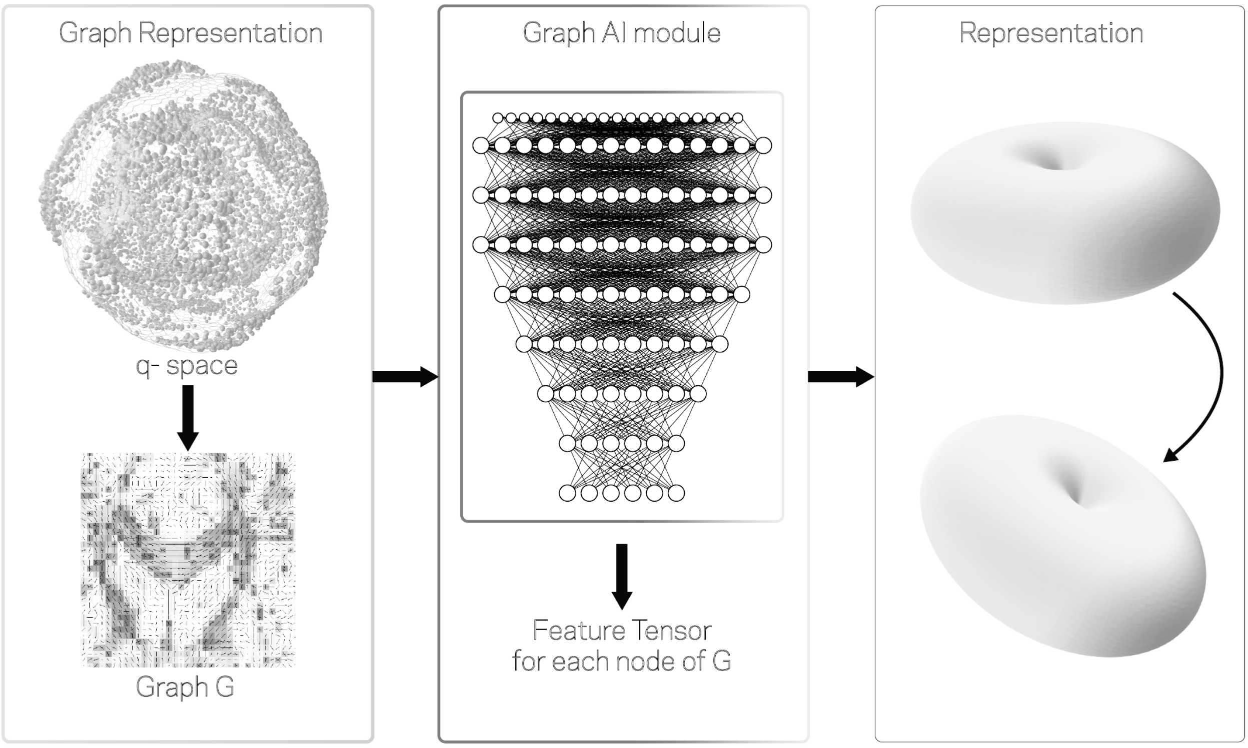

Figure: Tensor Diffusion diagram, Grap Representation of data entering the experimental model, Karolína Kotnour

Being sensible demands recognising the user, learning or knowing their preferences and the capability to exhibit empathy with the user's mood and current overall situation. Different users have different preferred modalities of interaction (e.g., auditory, visual, tactile, etc.), this is shaped by education or it could be affected by physical and cognitive capabilities. A system that wants to effectively engage with a user should be prepared to offer assistance in a variety of combinations. Humans have different attitudes towards privacy, generally this is a sensitive issue for most people and as such it should be approached with care and implemented with the assumption that the user value privacy and is allowed to set up how the system should deal with issues that relate to privacy. Safety is another important aspect a system will be forced to look after, given this systems primordial role is to assist humans, failing to preserve the safety of humans will render any such system worthless and unusable.Systems in this area are expected to have a degree of autonomy, the more autonomy the better, provided this does not come at the cost of other principles like safety. The system should be able to inform itself by learning from previous experiences and its intelligence should help adaptation to different circumstances in such a way that it does not require continuous programming.

A fundamental principle to be observed is that users should be always in control and should be able to decline advice from the system, impose their preferences, undo previous decisions and actions from the system and even disconnect the system altogether if it is perceived inconvenient. Systems of this type should be immersed in the environments we inhabit. Meaning their introduction to the environment and humans which were part of is the space is having to adapt to or change than the fundamental interactions and behaviours.

Quantum based model - HyperNEAT

Quantum theory in the context of architectural modelling describes a deeply interconnected world that recombines objectivity and subjectivity, quantitative and qualitative, mind and matter, into a unique model of Architectural Intelligence a reality.

Quantum models cope with two aspects: a particle aspect that we can physically measure as a finite size and shape and position in space at a moment in time, and a wave aspect that connects space and time. The quantum model of architecture is not based on shapes described by linear equations, but on fields of dynamic forces, waves and particles. Where the kinetics of particles and waves can be considered in their physical dimensions as problems of fluids, flow, turbulence, aerodynamics, or sound propagation. Space is never given by anything, but rather the result of an empirical body that determines the timing of its actions.

A major challenge for the field of Quantum Models and Architectural Intelligence is the development of neural network algorithms that can learn to perform many different tasks and learn with little domain-specific knowledge in real time.

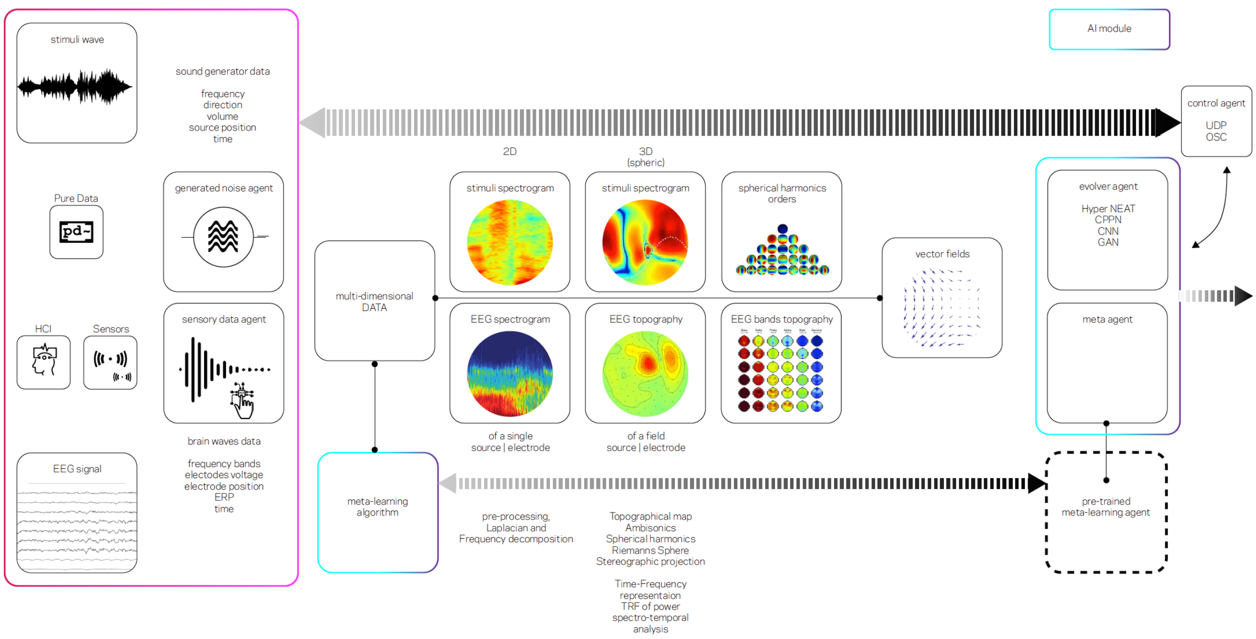

Figure: Data Flow Diagram, Meta Architecture Framework for Meta-Evolver, Karolína Kotnour

This research proposes a neuro-evolutionary algorithm for Architectural Intelligence and the quantum architecture model is based on HyperNEAT, Neuroevolution of Artificial Neural Network Topologies.[283], [284], [285], [286]

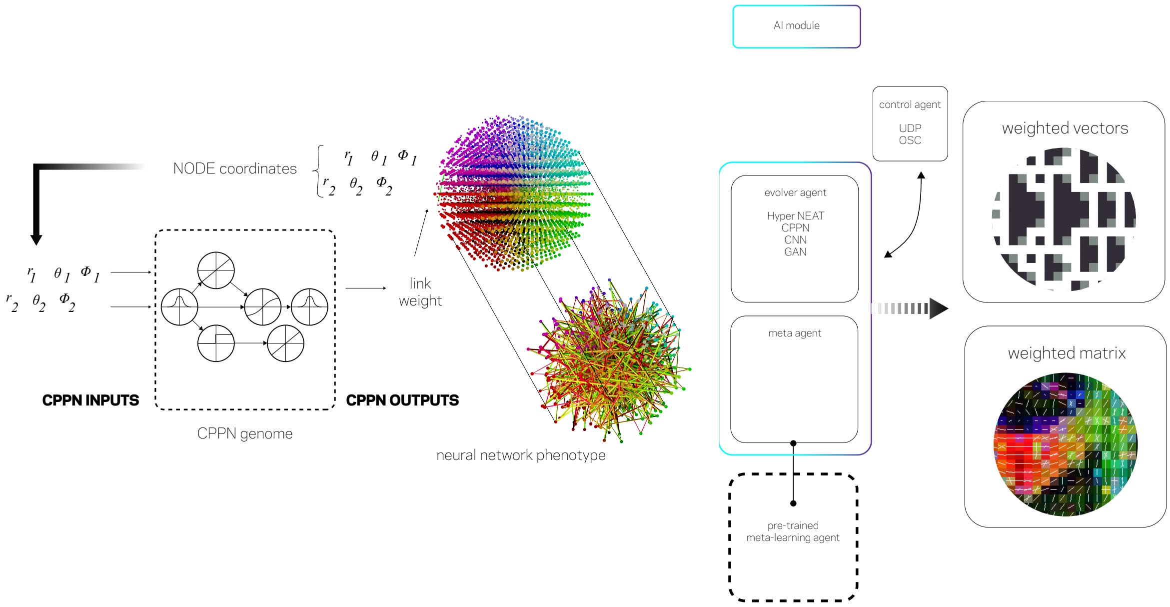

Figure: HypeNEAT algorithm for Quantum based Model - Meta Architecture Framework, Karolína Kotnour

HyperNEAT is an algorithm that works with spatial coordinates at the input to the machine learning algorithm and changes the value of the weight of each node of the neural network and at the same time the topology of this neural network and its connections.

It uses CPPN networks where, in this case, dynamic vector fields are input as variables representing the scenario of the dynamic environment of the sound model and the neural response.

283 Stanley, K. (2007). Compositional pattern producing networks: A novel abstraction of development. Genetic Programming and Evolvable Machines , 8(2):131–162.

284 Stanley, K. and Miikkulainen, R. (2002). Evolving neural networks through augmenting topologies. Evolutionary Computation , 10(2):99–127.

285 Stanley, K. and Miikkulainen, R. (2003). A taxonomy for artificial embryogeny. Artificial Life , 9(2):93–130.

286 Stanley, Kenneth O.; D'Ambrosio, David B.; and Gauci, Jason, "A Hypercube-Based Encoding for Evolving Large-Scale Neural Networks" (2009). Faculty Bibliography 2000s. 2178. https://stars.library.ucf.edu/facultybib2000/2178

These models were investigated and tested through designing digital environments.

Experimental works of dissertation

- Self-Evolved Architectures
- Meta Architecture
- Meta Evolver

5. Complex Dynamic Environment Model

The modelling of the complex dynamic systems and complex natural processes requires computers, and it is no coincidence that the development of computing has been significantly shaped by the building of computer models for simulating natural processes.

Church-Turing hypothesis stated that the Turing Machine cloud duplicate not only the functions of mathematical machines but also the functions of nature. John Von Neumann the other key figure in the development of computing, set out explicitly to create a theory which would encompass both natural and artificial biologies, starting from the premise that the basis of life was information.

A significant example to this dual approach in terms of evolutionary architectures approach and complex dynamic environment model is supported by the work of John Holland' s Adaptation in Natural and Artificial Systems. Holland starts by looking for commonality between different problems of optimisation involving complexity and uncertainty.

Environmental Properties

The learned models have the capability to perform increasingly complex tasks, the complexity of the simulated environments themselves should increase in order to continue to meaningfully challenge the algorithms and methods being explored. The fundamental dimensions of complexity that are implemented in the Complex Dynamic Environmental Models are: sensory, physical, cognitive, and social. In this research we are using AI that involve not only multidimensional sensory information, but a multidimensional control scheme in which actors-agents interact with the dynamic environment.

Complex Dynamic Environment Model - Sound Shape Space

Sensory Complexity - EEG, Brain Data, ERP

Physical Complexity - location in space, speed, volume, direction of sound source

Cognitive Complexity - or combinatorial complexity, requires a meta-learning approach

Social Complexity - *memory and cultural background of noise perception*

Sensory Complexity - The recent advances in Deep Learning have largely been driven by the ability of neural networks to process large amounts of visual, auditory, and text-based data.[287] ImageNet, a large database of natural images with associated labels, was essential in enabling models such as ResNet[288], and Inception to be trained to near human-level performance.[289] While ImageNet was mainly used for static image recognition tasks, its key component of visual complexity is necessary for many real-world decision making problems, such as self-driving cars, household robots, and Unmanned Autonomous Vehicles.[290] Additionally, advances in image processing algorithms, specifically around Convolutional Neural Networks, were the motivation for the pixel-to-control approach eventually found in the Deep-Q network.[291], [292]

Physical Complexity - Many of the applied tasks researchers are interested in solving using AI involve not only rich sensory information, but a rich control scheme in which agents can interact

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[287] LeCun, Y., Bengio, Y., & Hinton, G. (2015). Deep learning. Nature, 521(7553), 436.

[288] He, K., Zhang, X., Ren, S., & Sun, J. (2016). Deep residual learning for image recognition. In Proceedings of the IEEE conference on computer vision and pattern recognition (pp. 770-778).

[289] Russakovsky, O., et al. (2015). Imagenet large scale visual recognition challenge. International Journal of Computer Vision, 115(3), 211-252.

[290] Zhu, Y., et al. (2017, May). Target-driven visual navigation in indoor scenes using deep reinforcement
learning. In Robotics and Automation (ICRA), 2017 IEEE International Conference on (pp. 3357-3364). IEEE.

[291] Mnih, V., et al. (2015). Human-level control through deep reinforcement learning. Nature, 518(7540), 529.

[292] Juliani, Arthur & Berges, Vincent-Pierre & Vckay, Esh & Gao, Yuan & Henry, Hunter & Mattar, Marwan & Lange, Danny. (2018). Unity: A General Platform for Intelligent Agents.

with their dynamic environments in complex ways.[293],[294] The need for complex interaction often comes with the need for environments which replicate the physical properties of the target domain, typically the real world. This realism is essential to problems where the goal is to transfer a policy learned within a simulator to the real world, as would be the case for most robotics applications.[295], [296],[297]

Cognitive Complexity - A third track of complexity can be thought of as cognitive, or combinatorial complexity. The game of Go for example, which has long served as a test-bed for AI research, contains neither complex visuals nor complex physical interactions. Rather, the complexity comes from the large search space of possibilities open to the agent at any given time. [298],[299] Meaningful simulation environments should enable designers to naturally create such problems for the learning agents within them. These complex tasks might display hierarchical structure, a hallmark of human intelligence,[300] or vary from instance to instance, thus requiring meta-learning or generalization to solve.[301] The tasks may also be presented in a sequential manner, where independent sampling from a fixed distribution is not possible. This is often the

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293 Bicchi, A., & Kumar, V. (2000, April). Robotic grasping and contact: A review. In ICRA (Vol. 348, p.
353).

294 Levine, S., Finn, C., Darrell, T., & Abbeel, P. (2016). End-to-end training of deep visuomotor policies.
The Journal of Machine Learning Research, 17(1), 1334-1373.

295 Tobin, J., et al. (2017). Domain randomization for transferring deep neural networks from simulation to the real world. In Intelligent Robots and Systems (IROS), 2017 IEEE/RSJ International Conference on (pp. 23-30). IEEE.

296 OpenAI. (2018). Learning Dexterous In-Hand Manipulation.
https://d4mucfpksywv.cloudfront.net/research-covers/learning-dexterity/learning-dexteritypaper.pdf

297 Juliani, Arthur & Berges, Vincent-Pierre & Vckay, Esh & Gao, Yuan & Henry, Hunter & Mattar, Marwan & Lange, Danny. (2018). Unity: A General Platform for Intelligent Agents.

298 Müller, M. (2002). Computer go. Artificial Intelligence, 134(1-2), 145-179.

299 Silver, D., et al. (2017). Mastering the game of go without human knowledge. Nature, 550(7676),
354.

300 Botvinick, M. M. (2008). Hierarchical models of behavior and prefrontal function. Trends in cognitive
sciences, 12(5), 201-208.

301 Wang, J. X., et al. (2016). Learning to reinforcement learn. arXiv preprint arXiv:1611.05763.

case for human task acquisition in the real world, and the ability to learn new tasks over time is seen as a key-component of Continual Learning, and ultimately systems capable of Artificial General Intelligence.[302],[303],[304]

Social Complexity - The acquisition of complex skills via learning in mammals is believed to have evolved hand in hand with their ability to hold relationships within their social groups.[305] At least one strong example of this exists within the human species, with language primarily being the development of a tool for communication in a social setting. As such, the development of social behaviour among groups of agents is of particular interest to many researches in the field of AI. There are also classes of complex behaviour which can only be carried out at the population level, such as the coordination needed to build modern cities. Additionally, the ability for multiple species to interact with one another is a hallmark of the development of ecosystems in the world, and would be desirable to simulate as well. A simulation environment designed to allow the study of communication and social behaviour should then provide a robust multi-agent framework which enables interaction between agents of both the same population as well as interaction between groups of agents drawn from separate distributions.[306]

Artificial Life

In nature it is only the genetically coded information of form which evolves, but selection is based on the expression of this coded information in the outward form of an organism. The codes are manufacturing instructions, but their precise expression is environmentally dependent. This architectural model, considered as a form of artificial life, also contains coded manufacturing

302 Schmidhuber, J. (2015). On learning to think: Algorithmic information theory for novel combinations of reinforcement learning controllers and recurrent neural world models. arXiv preprint arXiv:1511.09249.

303 Schmidhuber, J. (2018). One Big Net For Everything. arXiv preprint arXiv:1802.08864.

304 Juliani, Arthur & Berges, Vincent-Pierre & Vckay, Esh & Gao, Yuan & Henry, Hunter & Mattar, Marwan & Lange, Danny. (2018). Unity: A General Platform for Intelligent Agents.

305 Arbib, M. A., et al. (2008). Primate vocalization, gesture, and the evolution of human language. Current anthropology, 49(6), 1053-1076.

306 Juliani, Arthur & Berges, Vincent-Pierre & Vckay, Esh & Gao, Yuan & Henry, Hunter & Mattar, Marwan & Lange, Danny. (2018). Unity: A General Platform for Intelligent Agents.

instructions which are environmentally dependent, but as in the real world model it is only the code script which evolves.

"IN NOISE CAN BE READ THE CODES OF LIFE, THE RELATIONS AMONG MEN. CLAMOUR, MELODY, DISSONANCE, HARMONY; WHEN IT IS FASHIONED BY MAN WITH SPECIFIC TOOLS, WHEN IT INVADES MAN'S TIME, WHEN IT BECOMES SOUND, NOISE IS THE SOURCE OF THE PURPOSE AND POWER, OF THE DREAM – MUSIC."

Jacques Attali, 1985

5.1 Experimental Works of Dissertation

5.1.1 Self-Evolved Architectures

The early stage of research experimentation with the simple neural networks and basic machine learning technics, outlined a need of more general framework for optimization and adaptation of architectural space. The basic generative methods as a results of the data processing from the digital environment could not reach the complexity of the proposed framework of Quantum-model for Architectural Intelligence. The genetic and evolutionary algorithms had to be applied to the model.

Experimental work published on GitHub

Appendix A: Self-Evolved Architectures

https://github.com/kaiakk/Self-Evolved-Architectures

Evolving Architecture

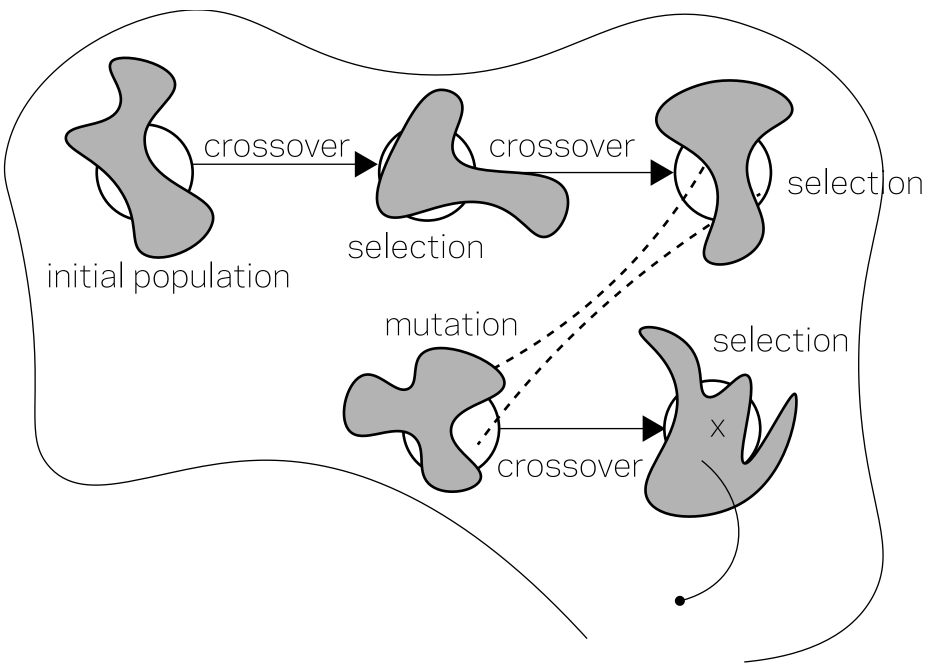

Figure: Schematic diagram of GA with evolutionary process

Evolving Architecture uses the features of natural design processes and relies on dynamic adaptation to environmental changes. The analogies of evolving architecture should be understood not only in terms of the applied natural processes of development of forms through natural selection, but also in the restless tendencies towards optimization and self-organisation that significantly improve the efficiency and power of diverse prototyping. Architecture is design to survive, design for life, and emphasizes the need for a responsible approach to the transformation and formation of energy and materials. The solution to dynamic environmental problems is to link architecture with a contextual understanding of the structure of nature. Traditional documentation of architectural production and construction design is replaced by code as a set of instructions and calculation formulas that reflect and adapt to a specific dynamic environmental and spatial context. The proposed approach to understanding and designing architecture introduces a set of instructions that John Frazer called "the genetic code of architecture."

At the same time, in computer science, methods inspired by the process of natural selection such as genetic algorithms have been developed widely, e.g .: design, games, image processing and robotics. Genetic algorithms are commonly used to generate high-quality solutions to optimization and search problems by relying on biologically inspired operators such as mutation, crossover and selection. A particular example is Hyper-NEAT, which can be used to transform 3D objects. The principle of the algorithm is the simple weight evolution in a topologically static neural network (CNE) or the evolutionary adaptation of the covariance matrix (CMA-ES) strategy, to the weight and topology evolution (NEAT) and intermediate weight coding (HyperNEAT). All algorithms encode artificial neural networks (ANNs), which are represented by weights and connectivity (also called topology). The first two algorithms only search the ANS weights, while the last two can also modify the topology.[307]

[307] Hausknecht, Matthew & Lehman, Joel & Miikkulainen, Risto & Stone, Peter. (2014). A Neuroevolution Approach to General Atari Game Playing. Computational Intelligence and AI in Games, IEEE Transactions on. 6. 355-366. 10.1109/TCIAIG.2013.2294713.

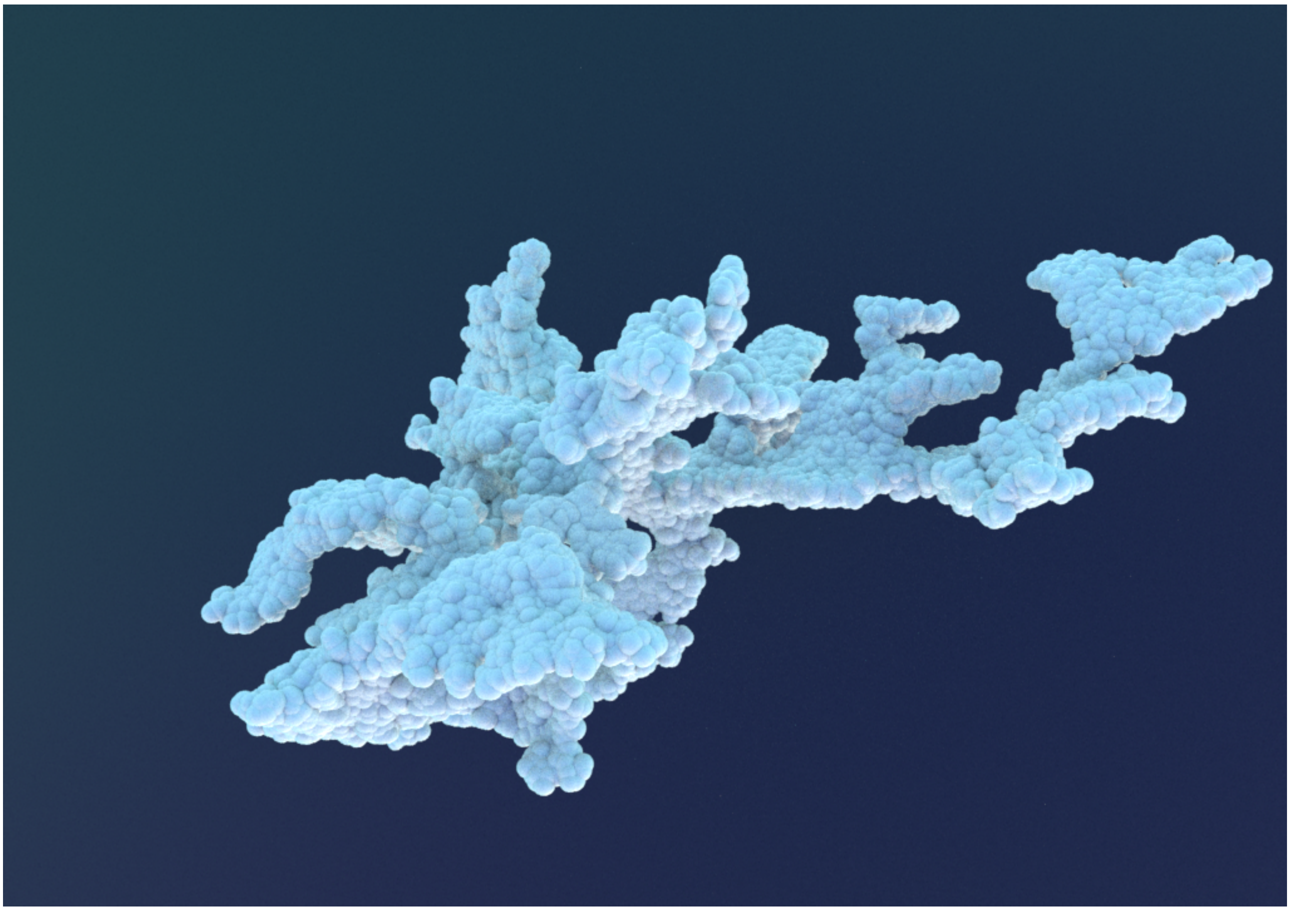

Figure: Evolutionary Architecture, Karolína Kotnour

5.1.2 Meta Architecture

The goal of Meta Architecture framework is to create new support tools in the form of software for researching and developing evolutionary architecture, that intervene and create relevant quality to the conditions of the environment. This research is fundamental to an architecture of the future that will be well adapted, in particular a flexible safe architecture that accommodates mass migrations and environmental climate crisis situations or global pandemics. Following framework was investigated through several experimentations with machine learning techniques.

Meta Architecture is a set of trained neural networks (artificial agents) that adapts quickly to the new environment. The neural networks are trained to learn something transferable that helps to generalize the situation or the scenario of the environment. Trained networks have a good performance after the adaptation stage, while it will update its current policy to fit its current environment.[308] Meta Architecture is not learning how to master a particular task but how to quickly adapt to new tasks. -Meta-Reinforcement Learning. Meta architecture is an intelligent agent (framework) that monitors the virtual world and intervenes to drive the architectural space forward according to some model of quality of experience.

Experimental work published on GitHub

Appendix B: Meta Architecture

https://github.com/kaiakk/Meta-Architecture

Meta-learning

Meta-learning goes by many different names: learning to learn, multi-task learning, lifelong learning, transfer learning, etc.

Transfer learning is the improvement of learning in a new task through the transfer of knowledge from a related task that has already been learned.

Human learners appear to have inherent ways to transfer knowledge between tasks. We recognize and apply relevant knowledge from previous learning experiences when we encounter new tasks. Machine learning algorithms, in contrast, traditionally address isolated tasks. Transfer learning attempts to change this by developing methods to transfer knowledge learned in one or more source tasks and use it to improve learning in a related target task.

Working with large data sets obtained from a changing environment requires advanced machine learning methods. In experimental part of the thesis various AI methods for modelling and generating new architectural forms. In particular, we use Transformers that work by using convolutional neural networks together with attention models, making them much more efficient than previous models. And although transformers were developed for sequence transduction processes such as speech recognition, translation, and text to speech, they can be also been

[308] Lisek, Robert B. , Meta-Learning, Proceedings of Art and Artificial Intelligence I Open Conference 2019 at ZKM Karlsruhe

implemented in the fields of computer vision, music generation and architecture. We used transformers for modelling adaptation and generation of architectural forms. We have previously tested recurrent neural networks RNN, long short term memory networks LSTM and VAE variational auto-encoders.[309] Transformer models consist of an Encoder and a Decoder. The Encoder takes the input sequence and maps it into a higher dimensional space (n-dimensional vector). That abstract vector is fed into the Decoder which turns it into an output sequence. The output sequence can be in another sequence of numbers, symbols, etc. The attention-mechanism looks at an input sequence and decides at each step which other parts of the sequence are important. We worked with sequences of numbers that represent position of architectural elements and angles of connections between them.

This approach for analyzing and creating evolving architecture is based on meta-learning. Meta-learning is the next generation of artificial intelligence systems. Meta-learning goes by many different names: learning to learn, multi-task learning, transfer learning, zero shot learning, etc. People easily transfer knowledge acquired in solving one task to another more general task. This means that we naturally recognize and apply previously acquired knowledge to new tasks. The more the new task is related to our previous experience, the easier we can master it. In contrast, popular machine learning algorithms deal with individual tasks and problems. Transfer learning attempts to change this by developing methods to transfer knowledge acquired in one or more source tasks and using them to improve learning in a related target task. The goal of transfer learning is to improve learning in the target task by using knowledge from the source task. Techniques enabling knowledge transfer will constitute significant progress in AI and and architecture.

The learning strategy was developed for a set of neural network modules that can be combined in various ways. Different modular structures were trained on a set of related tasks and generalize to new tasks, composing the learned architectural modules in a new way. For composing, can be used concatenation, in addition and product operators. The model quickly learn something about a new task based on previous tasks without requiring training model from scratch. The system finds two or more suitable modules that can be combined as optimal solution for a new task.

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309 Lisek, R., Meta Story Composer, Institute of Advaced Study CEU, 2020

Immersive digital spaces

An interesting direction of research on architecture is related to the problem of immersion, creating virtual environments and sound spatialisation. Virtual environments such as game environments also provide an excellent space for testing machine learning methods. Restrictions introduced during the pandemic motivated me to research potential of AI and virtual architecture for the evolution of society. This part of research and experimental work was focused on a roles of Presence, Flow, Immersion, and Interactivity. Presence is defined as the subjective experience of being in one place or environment, even when one is physically situated in another. Presence is a normal awareness phenomenon that requires directed attention and is based in the interaction between sensory stimulation, environmental factors that encourage and enable immersion. Flow is a state of experience where someone is completely absorbed and immersed in an activity. In the game environment created in Unreal Engine, were researched relations between presence, adaptation and interactivity, e.g. how interactivity and adaptation improves experience of presence. The 3D environment of an game engine proved to be an excellent platform for testing of the the meta-learning approach for architectural dynamic environment. The immersive architectural installations was presented during Siggraph Asia 2020 and on Institute of Electronic Arts NY.

Meta Architecture (MA) Framework

MA must generally look ahead into possible futures of the user's experience to determine the best intervention, if any, to bring about a structurally coherent experience.

MA user has opportunities to act, lead, MA must continuously project and select possible future scenarios.

Criteria, principles, goals, and aesthetic considerations are provided by an architect.

Virtual character autonomy. The characters in the virtual world can have more or less autonomy from the MA.

5.1.3 Meta Evolver

Meta-Evolver[310] is a tool for a visual representation of the various dynamic environment models that correlate in multi-layered system. Meta-Evolved provides the environment for testing dynamic spatial adaptation, where the environment is composed of algorithms and parametric definitions.

Figure: Evolving Architecture, based on Meta Architecture Framework, 2020, Meta-Evolver tool Karolína Kotnour.

Experimental work published on GitHub

Appendix C: Meta-Evolver
https://github.com/kaiakk/Meta-Evolver

This research uses advanced AI methods (meta-learning) and cutting-edge technologies including immersive environments and virtual reality (VR) to offer innovative methods of architectural creation. The ability to continuously learn and adapt from limited experience in a dynamic environment is an important milestone on the path towards building interactive spaces in modern architecture. We developed the tool Meta-Evolver for testing spatial adaptation in dynamic environments and integrated the ability for interaction with a human user.

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[310] http://vr.molab.eu/meta-evolver/

The project proposes a new strategy for creating evolving architectural structures based on the idea of adaptation to a dynamically changing environment and with the use of advanced machine learning and AI methods. The evolving architecture uses physical and virtual processes that are transformed and assembled into structures based on environmental properties and capabilities. The computational models are used for processing of a dynamic multidimensional forces, are they suitable to be integrated in an environmental intelligent models for architectural spatial adaptation? In to what extent are they capable to grasps composed spatial dynamical forces, and define the edges and trajectories of the self-evolved architectural environment? The project investigates a living dynamic system as a complex set of natural and cultural sub-processes in which each of the interacting entities and systems creates complex aggregates. It deals with natural processes, communication flows, information networks, resource distribution, dense noise masses, a large group of agents and their spatial interactions in the environment. By significantly expanding existing research, the project creates a meta-learning model useful for testing aspects of adaptation to a complex dynamic environment. This refers to the difficulty of designing artificial agents that can intelligently respond to evolving complex processes.

Evolving Architecture

Evolving Architecture is a large field with a few subfields such as Prescribed, Responsive, Interactive and Evolutionary or Living Systems. Each of these areas need different expertise and often focused on certain interaction strategies and techniques as practiced by people like Michael Fox, Rachel Armstrong, Philip Beesley or Heatherwick and UN Studio. Evolving Architecture uses the features of natural design processes and relies on dynamic adaptation to environmental changes. The analogies of evolving architecture should be understood not only in terms of the applied natural processes of development of forms through natural selection, but also in the restless tendencies towards optimization and self-organisation that significantly improve the efficiency and power of diverse prototyping. Architecture is designing for survival, designing for life, and emphasizes the need for a responsible approach to the transformation and formation of energy and materials. The solution to dynamic environmental problems is to link architecture with a contextual understanding of the structure of nature. Traditional documentation of architectural production and construction design is replaced by code as a set of instructions and calculation formulas that reflect and adapt to a specific dynamic environmental and spatial context. The proposed approach to understanding and designing architecture introduces a set of instructions and general principles of interaction with the environment.[311] It is also necessary to create large groups of researchers, architects and urban planners that change and adapt the architecture of our cities and suburban to the new needs of their inhabitants.

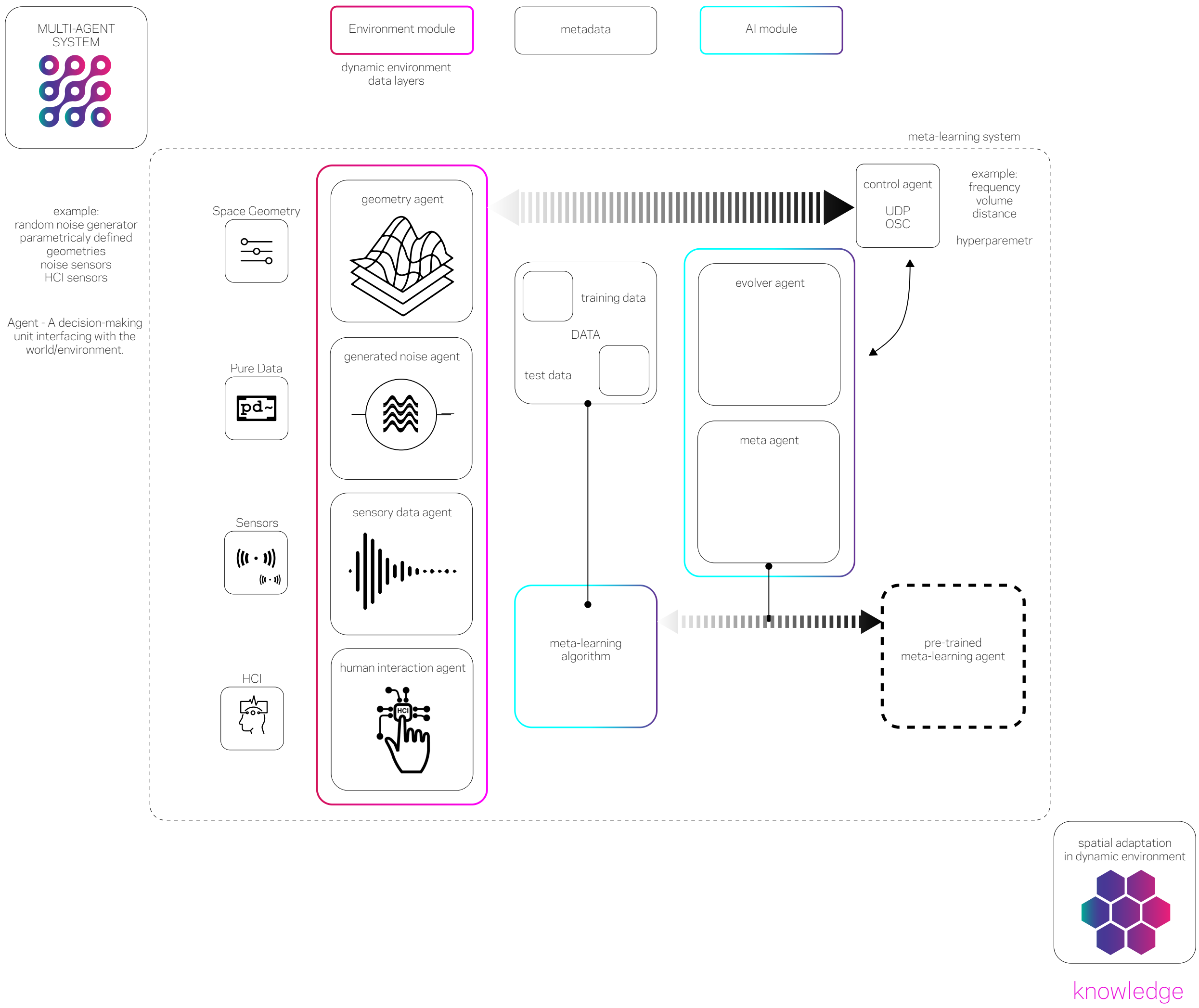

Figure: Meta-Evolver Framework diagram, Karolína Kotnour

At the same time, in computer science, methods inspired by the process of natural selection such as genetic algorithms have been developed widely, e.g .: design, games, image processing and robotics. Genetic algorithms are commonly used to generate high-quality solutions to optimization and search problems by relying on biologically inspired operators such as mutation, crossover and selection. A particular example is Hyper-NEAT, which we used to transform 3D objects. The principle of the algorithm is the simple weight evolution in a topologically static neural network (CNE) or the evolutionary adaptation of the covariance matrix (CMA-ES) strategy, to the weight and topology evolution (NEAT) and intermediate weight coding

311 Frazer, John. 1995. An Evolutionary Architecture. London: Architectural Association Publications.

(HyperNEAT). All algorithms encode artificial neural networks (ANNs), which are represented by weights and connectivity (also called topology). The first two algorithms only search the ANS weights, while the last two can also modify the topology.

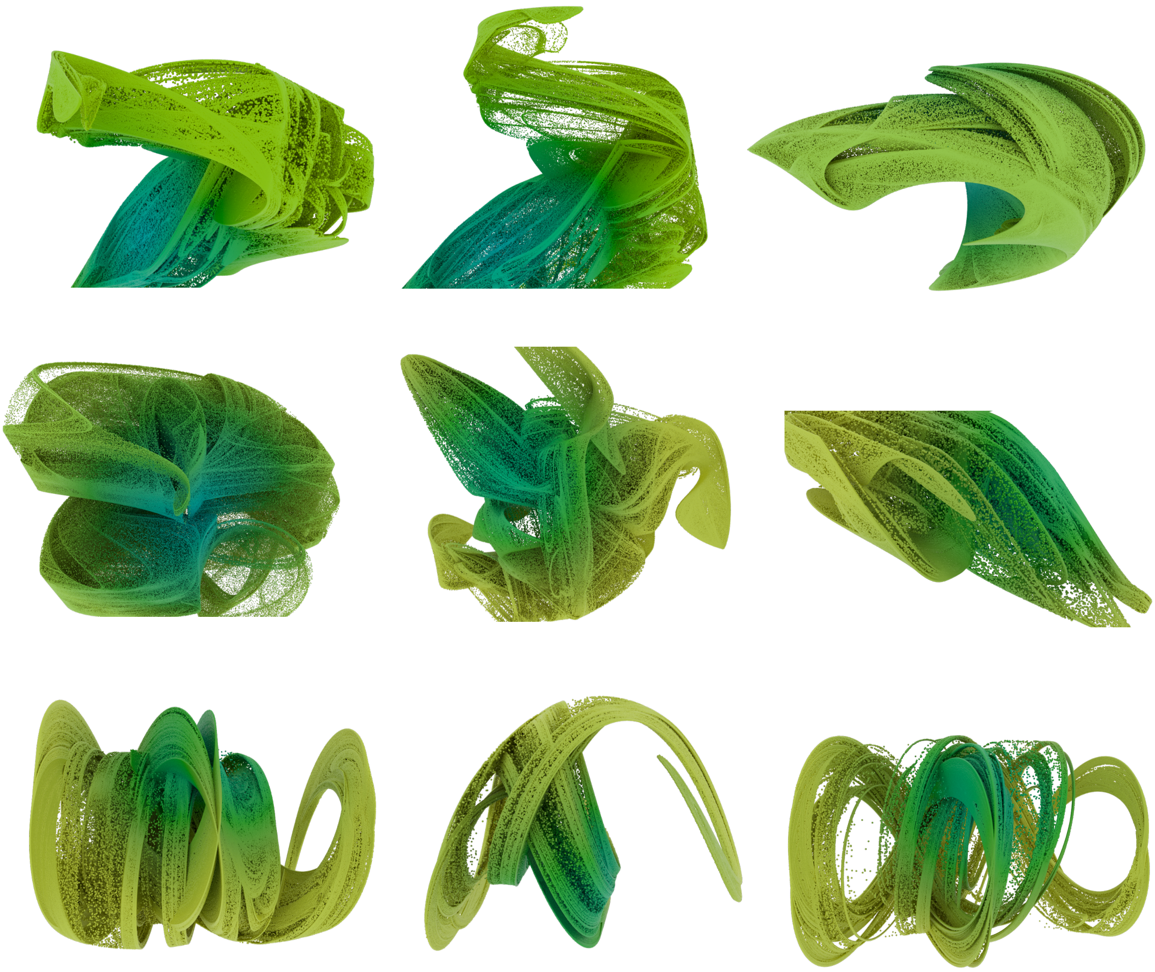

Figure: Evolving Architecture, based on Meta Architecture Framework, 2020, Meta-Evolver tool Karolína Kotnour.

This model proposes a neuro-evolutionary algorithm for Architectural Intelligence and the quantum architecture model is based on HyperNEAT, Neuroevolution of Artificial Neural Network Topologies.[312], [313], [314], [315]

[312] Stanley, K. (2007). Compositional pattern producing networks: A novel abstraction of development. Genetic Programming and Evolvable Machines , 8(2):131–162.

[313] Stanley, K. and Miikkulainen, R. (2002). Evolving neural networks through augmenting topologies. Evolutionary Computation , 10(2):99–127.

[314] Stanley, K. and Miikkulainen, R. (2003). A taxonomy for artificial embryogeny. Artificial Life , 9(2):93–130.

[315] Stanley, Kenneth O.; D'Ambrosio, David B.; and Gauci, Jason, "A Hypercube-Based Encoding for Evolving Large-Scale Neural Networks" (2009). Faculty Bibliography 2000s. 2178. https://stars.library.ucf.edu/facultybib2000/2178

The Genetic Code of Architecture perform the adaptation through changes in genetic configurations, which is primarily a search for coadapted sets of various forms of genes which together significantly augment the performance of the corresponding composite observable characteristics of an architectural style, or architectural organism. The technical word phenotype is used for the bodily manifestation of a gene, the effect that a gene, in comparison with its alleles, has on the body, via development. The phenotypic effect of some particular gene might be, say, green eye colour. In practice most genes have more than one phenotypic effect, say green eye colour and curly hair. Natural selection favours some genes rather than others not because of the nature of the genes themselves, but because of their consequences— their phenotypic effects. Genes, then, reach outside their 'own' body to influence phenotypes in other bodies.[316] The phenotype is the product of the balanced and harmonious interaction of all genes. Natural selection will tend to bring together those genes that constitutes a balanced system. The process by which genes are accumulated in the gene pool that collaborate harmoniously is called "integration" or " coadaptation." The result of this selection has been referred to as "internal balance."[317] The genes act in many ways, affecting many physiological and morphological characteristics which are relevant to survival. All of these come together into the sufficient parameter “fitness” or selective value. Similarly environmental fluctuation, patchiness, and productivity can be combined of environmental uncertainty.[318] The genetic adaptive plan develops in terms of an ever-changing population of chromosomes which, interacting with the environment, provides a concurrent sequence of phenotype populations. For many purposes, it is convenient to represent a_l population as a probability distribution over the set of genotypes a_l , where the probability assigned to genotype A E: a_l is the fraction of the total population consisting of that genotype.[319],[320]

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[316] Dawkins, Richard. 2006 The selfish gene. Oxford New York: Oxford University Press, 2006.

[317] Mayr, Ernst. 1963. Animal Species And Evolution. Cambridge, MA, USA: Belknap Press of Harvard University Press.

[318] Levins, Richard. 1968. Evolution In Changing Environments: Some Theoretical Explorations. Princeton, N.J., USA: Princeton University Press.

[319] Holland, John H. 1992. Adaptation In Natural And Artificial Systems: An Introductory Analysis With Applications To Biology, Control, And Artificial Intelligence. 1st ed.. Cambridge, Mass: M.I.T. Press.

[320] Crow, James F. and Motoo Kimura. “An introduction to population genetics theory.” (1970).

Evolutionary Algorithms

Evolutionary algorithms is a term used to describe computer-based problem solving systems which use computational models of some of the known mechanisms of evolution as key elements in their design and implementation. They all star a common conceptual base of simulating the evolution of individual structures by processes of selection, mutation, and reproduction. The processes depend on the perceived performance of the individual structures as defined by and environment.

More precisely, EAs maintain a population of structures, that evolve according to rules of selection and other operators, that are referred to as “search operators”, (or genetic operators), such as recombination and mutation. Each individual in the the population receives a measure of its fitness in the environment. Reproduction focuses attention on high fitness individuals, this exploiting (exploitation) the available fitness information. Recombination and mutation perturb those individuals, providing general heuristics for exploration. EAs use stochastic processes, but the result is distinctly non-random.

Genetic algorithms (GA), can be seen as a software tool that tries to find structure in data that might seem random, or to make a seemingly unsolvable problem for more or less solvable. GAs can be applied to domains about which there is insufficient knowledge or the size and complexity is too high for analytic solution. (Anon) Examples are finding a best-fit solution, not necessarily the perfect solution, for crew and team planning, delivery itineraries, finding the most beneficial locations for stores or warehouses, building statistical models (Anon) and game playing behaviour.[321] The genetic algorithm is a model of machine learning, stochastic optimisation strategy which derives its behaviour from a metaphor of some of the mechanisms of evolution in nature. Genetic algorithms are used for a number of different application areas, an example is multidimensional optimisation problems in which the character string of the chromosome (machine of a population of individuals, arrays of bits or characters) can be used to encode the values for the different parameters being optimised.

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Meta-learning

Deep artificial neural networks (DNNs) are multilayers networks of nodes and connections between nodes (weights) typically trained via gradient-based learning algorithms, namely backpropagation. The next step was to research and implement Evolutionary Strategies, which means transformation of architectural objects in time. This can be done by modifying selected layers in the neural network or by using the population-based genetic algorithm (GA). We evolve the weights of a Deep Neural Network by applying additive Gaussian noise in such a way that the general features of the training class of 3d objects are kept, but its evolution is possible. We created a mechanism for controlling hyperparameters of the neural network and ipso facto for controlling generated output numbers that represent new 3d objects. In this way it is possible to create a fully universal object generator, and propose a new method of designing complex original architectures. Evolution strategy described above is a step toward research focused on the self-organization of complex structures from random elements. This method is general enough to become the starting point for meta-learning research and creating universal toolkit that supports architects or designers.

Meta-Evolver Framework

The framework for the adaptive agent-based model for dynamic environments based on data of generated random numbers and soundscape was defined. We outlined and established the architectural strategy of the multi-platform system for generative modelling based on input datasets. The framework for a visual representation of the dynamic models and generated resulting correlated layers. The main task was adapting an agent to new environments and create a new multi-agent environment as well as architecture for testing aspects of continuous adaptation. The whole model was parameterised and the communication protocols integrated into the digital environment. The method was to present dynamics as a sequence of tasks and train agents to use the dependencies between successive tasks. We created a meta- learning model for the problem of continuous adaptation of an artificial agent in a complex dynamic environment.

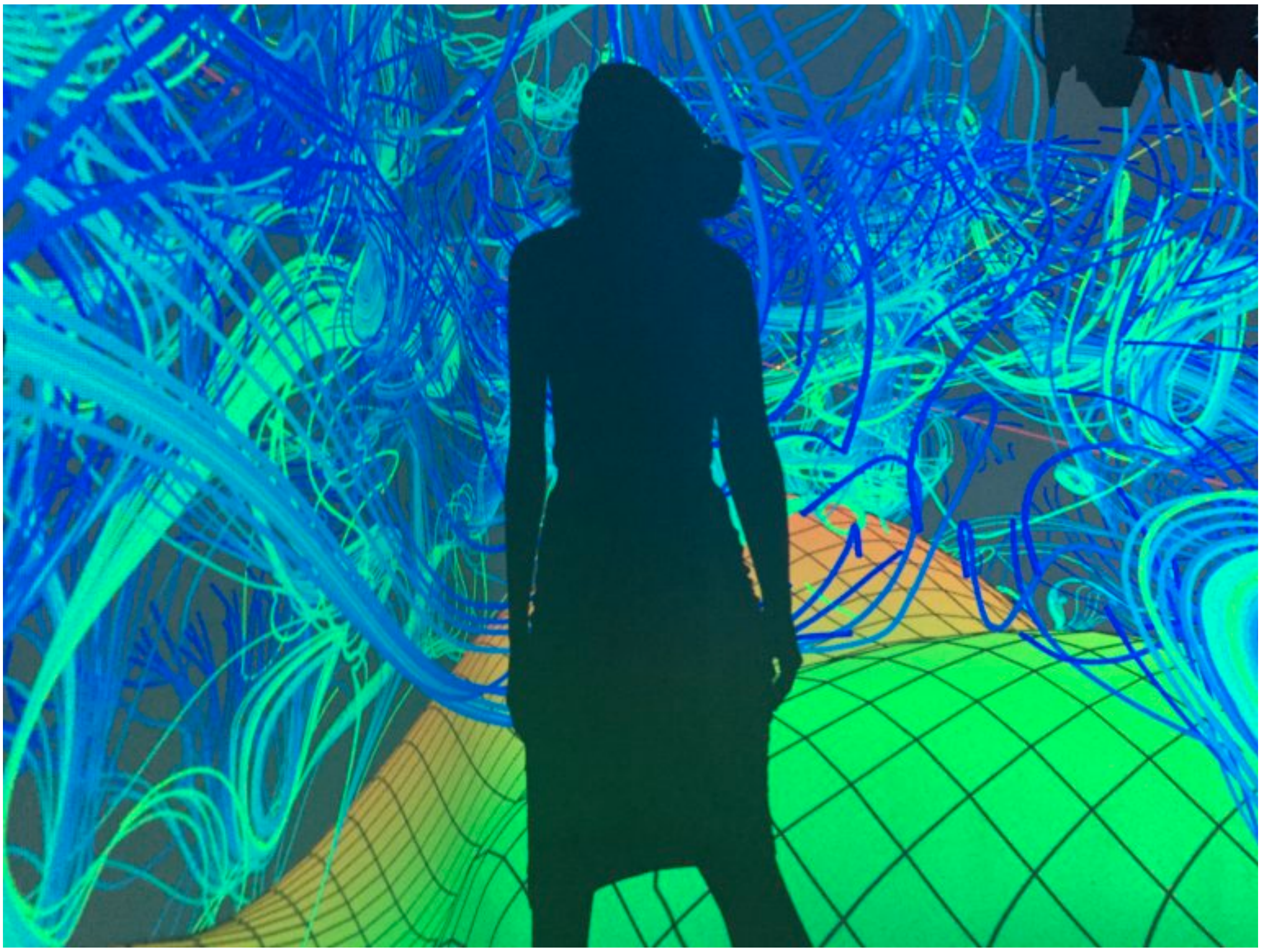

Figure: Meta-Evolver, Immersive Installation, 2020, Karolína Kotnour, VR

The observation-based research on these generated correlations was conducted and defined the possible dispositions of forming patterns and structures, the model can be applied to various dynamic environments and after pre-training of agents can effectively adapt and, generate architectural dispositions, structures, and environments. The parallel task of my research was the problem of creating virtual interactive environments (VE). We were focused on the roles of Presence, Flow, Immersion, and Interactivity. Presence is defined as the subjective experience of being in one place or environment, even when one is physically situated in another. Presence is a normal awareness phenomenon that requires directed attention and is based on the interaction between sensory stimulation, environmental factors that encourage involvement and enable immersion. Flow is a state of experience where someone is completely absorbed and immersed in an activity. We researched relations between presence, flow, immersion, and interactivity, e.g. how interactivity and sound spatialization improves the experience of presence. The three different and complementary 3D environments and experiments: 1) adaptation in a dynamic environment created by changes in the structure of the parametrized environment; 2) adaptation in a multi-agent environment created by the presence of multiple learning actors (interdepended datasets, transformation matrices), and 3) adaptation in a dynamic environment created by the interaction of a human user with an adaptive artificial agent. The immersive dynamic environment is created by using virtual reality (VR) and sound synthesis. The model keeps the transformation of 3D objects and sound synthesis as synchronous processes.

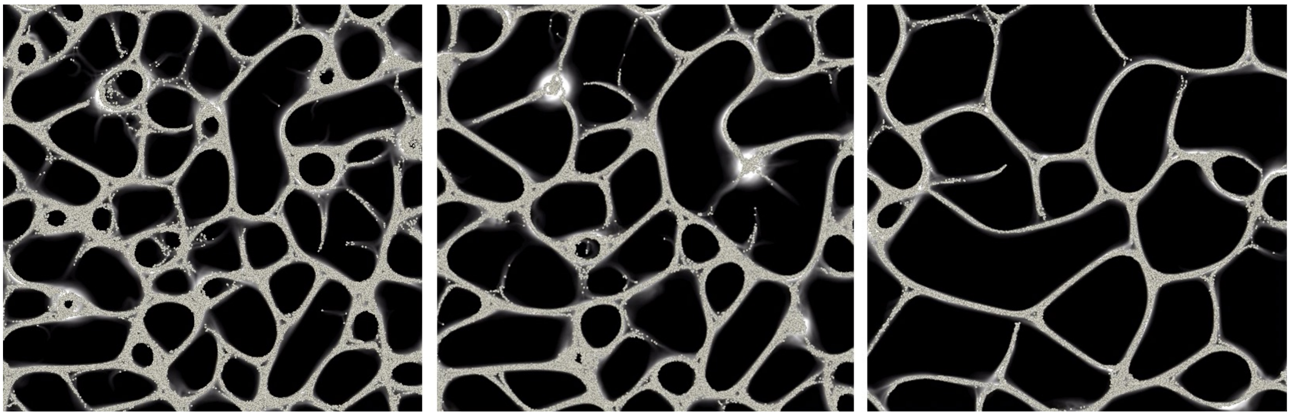

Figure: Evolutionary Self-Organization, 2020, Karolína Kotnour.

Dynamic environments

The urban and architectural structures are complex multi-dimensional structures in which natural processes and interactions of large groups of agents, communication flows, information networks, and others are intertwined. The above structures undergo continuous transformations. A dynamic environment is any space that surrounds us and the structure of which changes over time or is modified by groups of agents. There are closed spaces with relatively well-defined boundaries and others that do not have well- defined boundaries, which we can call open spaces. These environments are usually rich, complex, unpredictable, and can generate significant "noisy" data, unstructured and sometimes very dynamic changes.

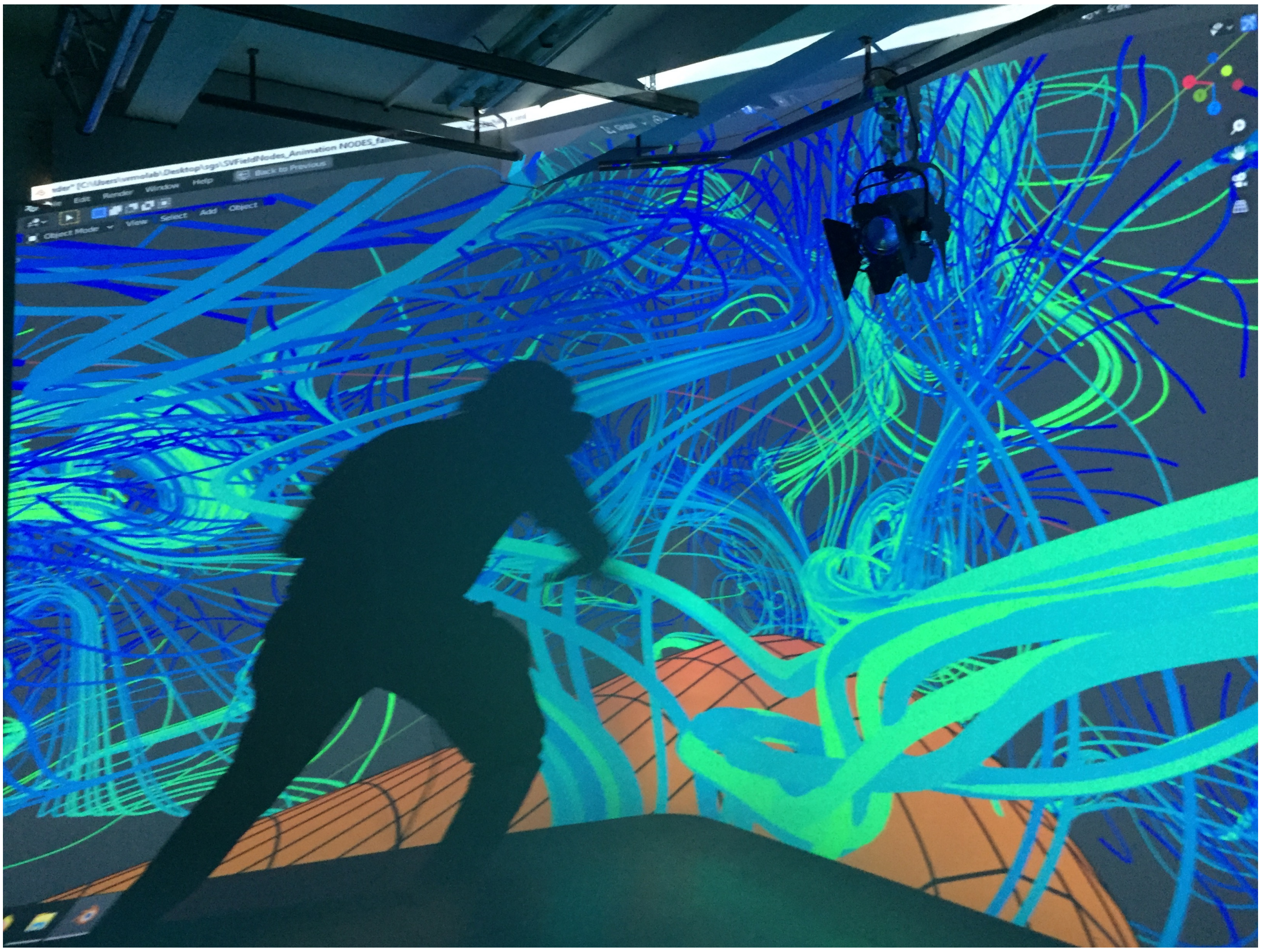

Figure: Meta-Evolver, Immersive Installation, 2020, Karolína Kotnour, VR.

6. Conclusion and Future work

The Advanced Architecture Approach is in digital writing and coding of life. The digital articulations of artificial life, and the diversity of artificial entities are depending on the levels of abstraction from the complexity of multilayered environment. The writing and coding as a core proficiency of architects represents a radical revolution for architectural design. While this techniques relies on the one hand on the advances in computational power of computers and computational technologies and on the other hand on the power of digital representation, and intervention to the environment. The Advanced Architecture Approach works with digital models that are either rule based models, control based models, or quantum based models. Where the quantum models describes a deeply interconnected world that recombines objectivity and subjectivity, qualitative and quantitative, mind and matter, into a unique model of reality.

Neural networks are universal function estimators. Universality means that neural networks can approximate many different complex functions. The main idea of neural networks is to build up representations for complicated functions using compositions of relatively simple functions, which are called layers. The proposed model suggest combination of simple functions in more complex functions that defines architectural environments and demands on architecture that *Architectural Intelligence* system can learn. Machine learning tools are support tools for improving design processes. They are form of navigation system for an architect whose role is that of an operator of the design processes and who maintain the intelligent system during learning.

The proposed *Architectural Intelligence* model of neuro-evolution and meta-learning models provides variability and flexibility in dynamic environments. Meta-learning approach provide sustainable possibility of implementing already tested and trained models from other domains and areas of machine learning to the field of architecture. The above research is fundamental to an architecture of the future that will be well adapted, to the changes defined as differentiations of the environment, in particular resilient architecture that accommodates mass migrations and environmental climate crisis situations or global pandemics.

Meta Architecture and Self-Evolved Architecture frameworks investigates fundamental form-generating processes in architecture, paralleling a wider scientific search for a theory of evolution in the natural world. In evolutionary processes, the new forms are created by structural modifications of old forms. An evolutionary environment maintains a hierarchy of long and short term purposes and modifications, where each of this purpose has its own dominant periodicities. The domain of Evolutionary Architecture is a large field with a few subfields such as Responsive, Interactive and Evolutionary or Living Systems. Where each of these areas need different expertise and often focuses on certain interaction strategies and techniques.

The fundamental need and motivation for communication and movement is determined by physiological and psychological possibilities and needs of living organisms. Naturally these processes, which are largely determined by available technologies, creative and intellectual activities, are in the balance of all layers of architectural environment.

The character of space is given by the ability to communicate and the need to communicate and understand.[322] The resulting architecture should be able to accommodate these human needs as flexibly as it adapt and assimilate dynamic forces of the environment.

The *Architectural Intelligence* allows to communicate and interact with the inner and outer space in time and in constant tension of two dynamic forces. The structure of meta-space suggested in this thesis primarily create for its user-creator-agent environment based on the uniqueness and users perception of the environment.

Neural Architecture Search and Future work

The architects are engaged in designing systems containing the architectural problems and computational models for their solutions. The future challenges and demands on meta-learning or quantum-learning consist of capability of self-observation of the routine in creative design process, the perception action loop.

In terms of Architectural Intelligence the new support tools in the form of software for researching and developing evolutionary architectures should be build.

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