Näited

1. Jääpurikate mudel

L. Makkonen. Models for the growth of rime, glaze, icicles and wet snow on structures. Phil. Trans. Royal Soc. London, A, 2000, 358, 2913-2939.

2. Liivadüünid

Komarova, A.C. Newell. Nonlinear dynamics of sand banks and sand waves. Fluid Mech., 2000, 415, 285-321.

3. Ämblikuvõrk

F. Vollrath, D.P. Knight. Liquid crystalline spinning of spider silk. Nature, 2001, 410, 541-548.
J. Engelbrecht. Challenges for tensile stresses. Proc. Estonian Acad. Sci. Engng., 2002, 8/2, 134-142.

4. Turbulents

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5. Galaktikate kärgstruktuur

J. Einasto a.o. A 120-Mpc periodicity in the three-dimensional distribution of galaxy superclusters. Nature, 1997, 385, 139-141.

6. Kiirrongi mudel tunnelis

M. Howe, M. Jida, T. Fukuda, T. Maeda. Theoretical and experimental investigation of the compression wave generated by a train entering a tunnel with a flared portal. J. Fluid Mech., 2000, 425, 111-132.

7. Kortsutatud paber

G. Gompper. Patterns of stress in crumpled sheets. Nature, 1997, 386, 439-141.
M. Ben Amar, Y. Pomeau. Crumpled paper. Proc. Royal Soc. London, A 1997, 453, 729-755.

8. Modelleerimine bioloogias

P. Kohl, D. Noble, R.L. Winslow, P.J. Hunter. Computational modelling of biological systems: tools and visions. Phil. Trans. Royal. Soc. London, A 2000, 358, 579-610.

9. Modelleerimine nanoskaalas

Z. Toroczkai, E.D. Williams. Nanoscale fluctuations at solid surfaces. Physics Today, 1999, Dec., 24-28.

10. Keerukad süsteemid

Nature Insight: Complex systems, 2001, 410, 241-284.

11. Modelleerimise üldprobleemid

J. Engelbrecht. Complexity and simplicity. Proc. Estonian Acad. Sci. Phys. Math., 1993, 42, 1, 107-118.
J. Engelbrecht. Teadusest uue sajandi künnisel. Akadeemia, 2000, N 6, 1204-1222.

Näide: liivakuhikud ja liivadüünid

1. Düünid looduses
2. Lihtne liivakuhiku mudel
3. Täpsustatud liivakuhiku mudel
4. Osakeste kuju mõjutab varinguid
5. Mis juhtub konvektsioonis

vt. Loeng 11 vt. Loeng 14

Näide: kaose “mäng”

1 Kaose “mäng” kolmnurgas
2 Kaose “mäng” nelinurgas
3 DNA analüüs

Viiteid:

1 Peitgen H.-O., Jürgens H., Saupe D., Chaos and Fractals, Springer, New York et al., 1992.
2 Peak D., Frame M. Chaos under Control. Freeman, New York, 1994.

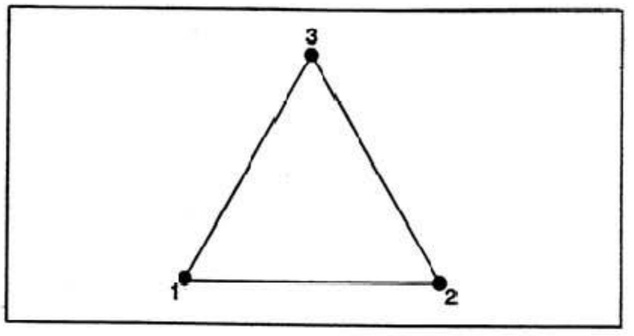


Figure 6.1 : The game board of our first chaos game.

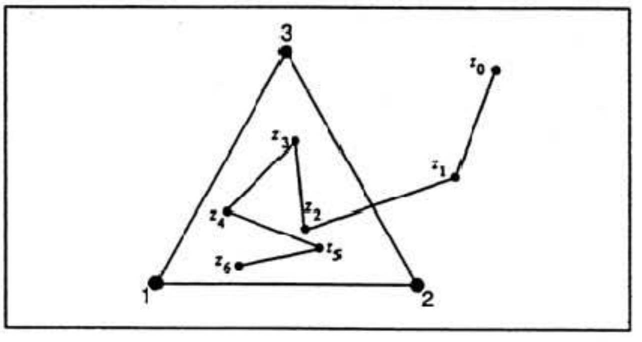


Figure 6.2 : The first six steps of the game. Game points are connected by line segments.

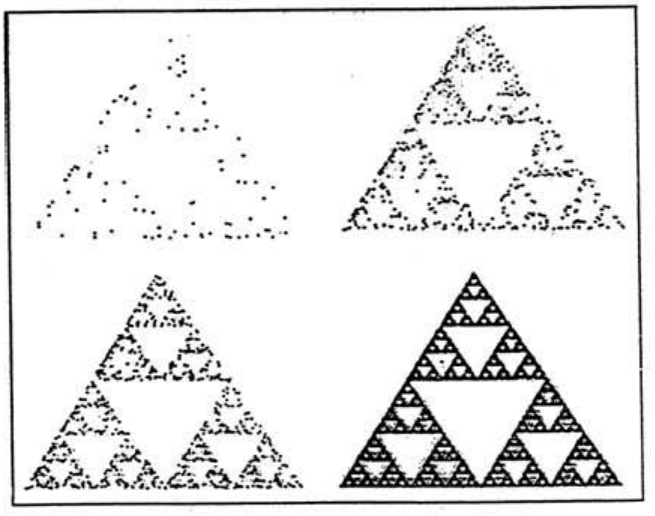
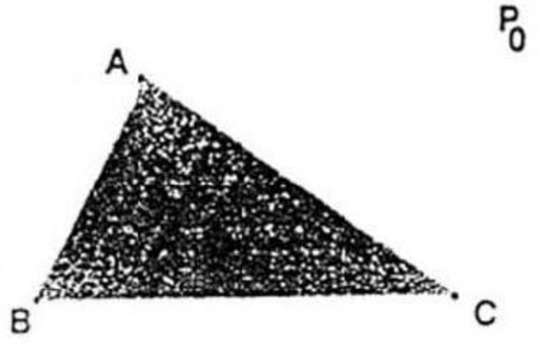
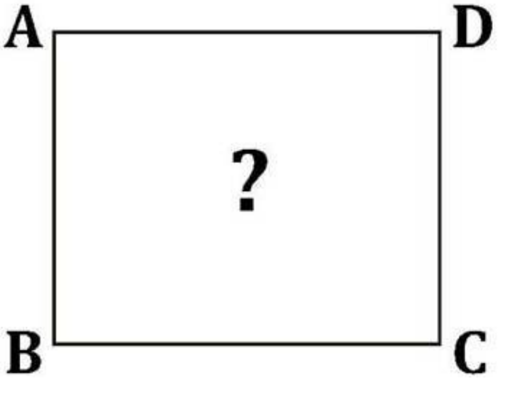


Figure 6.3 : The chaos game after 100 steps (a), 500 steps (b), 1000 steps (c), and 10,000 steps (d). Only the game points are drawn without connecting lines. (Note that there are a few spurious dots that are clearly not in the Sierpinski-gasket.)



The Chaos Game (Three Corners, Two-thirds Version)



Four Corners, One-half Version

DNA is composed of four chemically different building blocks, called bases, which are designated by the letters A, C, G, and T. All biological information is thought to be encoded in "words" spelled from these letters. If we look at the string of A's, C's, G's, and T's making up a given gene (a piece of DNA encoding the rules for making a protein), it's very hard for the untrained eye to see much rhyme or reason in it. Here's an example, using the first 250 or so bases in the DNA coding for the enzyme amylase:

GAATTCAAGTTTGGTGCAAAACTTGGCACAGTTATCCGCAAG
TGGAATGGAGAGAAGATGTCCTATTTAAAGTAAATATATACG
ATTTTGTCATTTGTTCTGTCATACATCTGTTGTCATTTTCTTAA
ATATTGTAACTTAAATTGTTGATTATTAGTTAGGCTTATTGTT
CATTTATCCTTAATTAATTATGTTTTTCATTTGATACATCAGT
CACCTGATAACAGCTGAAATCTAAAGTATCACTTAGTGAGTT
TTGTTGGGTTGTGTT

But if we make a square with corners labeled A, C, G, and T, take a starting point in the middle of the square, and then play the Chaos Game by going halfway to a previous point from the vertex whose letter appears next in a given DNA string (many such strings have been identified, in everything from primitive organisms to humans), some of the syntax of this code jumps out.

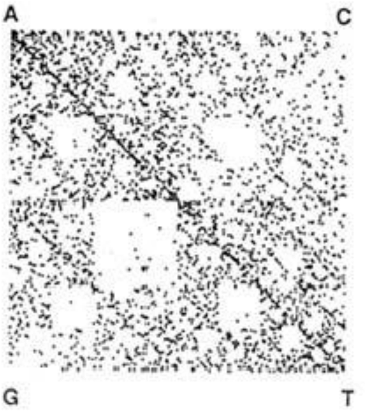


Figure 1.23 *Four-cornered Chaos Game picture generated by the DNA encoding the enzyme amylase.*

Figure 2.27 *Amylase DNA IFS square with empty regions marked.*

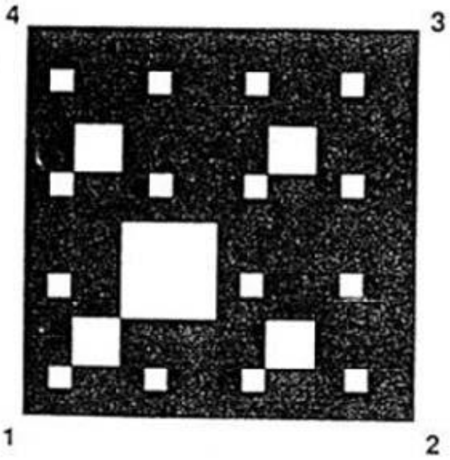


Figure 2.26 *Some holes in an otherwise filled-in square made by the random IFS algorithm plus the condition that rule* 1 *cannot follow rule* **3**.

Näide: jäätumise mudel

1. Protsessi olemus
2. Märg ja kuiv jäätumine
3. Kuidas “kasvab” jääpurikas
4. Arvutuslik mudel

Viiteid:

Makkonen L. Models for the growth of rime, glaze, icicles and wet snow on structures. Phil. Trans. Royal Soc. London. A, 2000, 358, 2913-2939.

10.1098/rsta.2000.0690

THE ROYAL SOCIETY

Models for the growth of rime, glaze, icicles and wet snow on structures

By Lasse Makkonen

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Ice accretion on structures is discussed with an emphasis on estimating structural design iceloads and solving operational icing problems. Basic principles of modelling of icing caused by freezing precipitation, cloud droplets and wet snow, as well as simulation of icicle growth, are presented. Theoretical models of atmospheric ice accretion are critically reviewed, particularly with respect to the simulation of the relevant physical processes. The reasons for the difficulties in simulating some icing phenomena accurately are analysed and proposals for further improvements in the models are made.

Keywords: ice; ice accretion; structures; icing; icicles; modelling

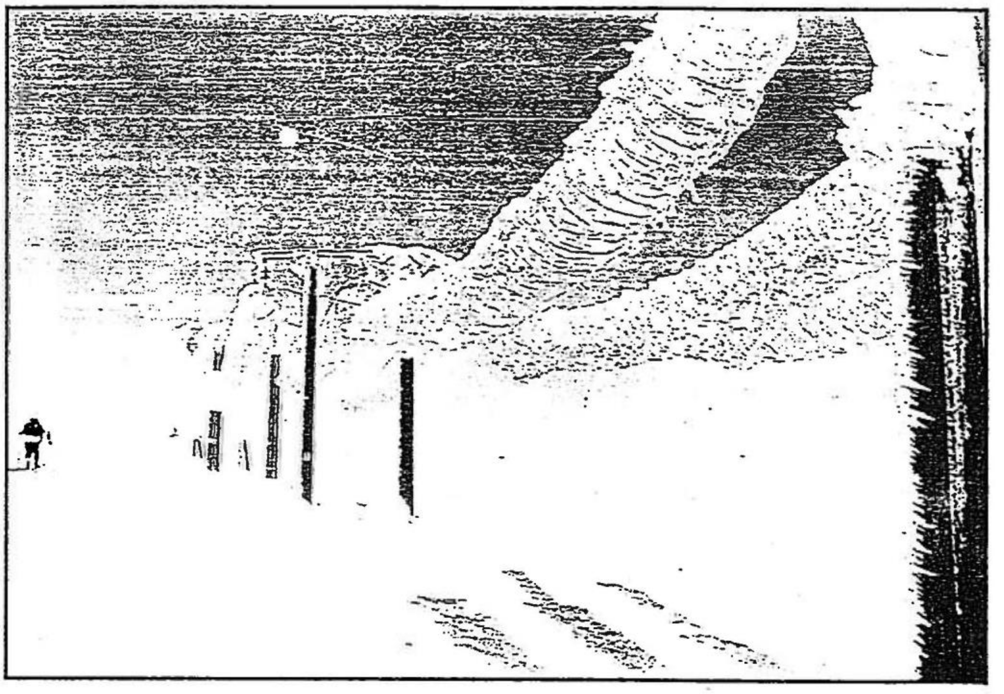

Figure 1. Rime on a 22 kV overhead line in Voss, Norway, 18 April 1961. This event is the highest iceload recorded on power lines in the world: 305 kg m^{-1} on each span (photograph from Olav Wist).

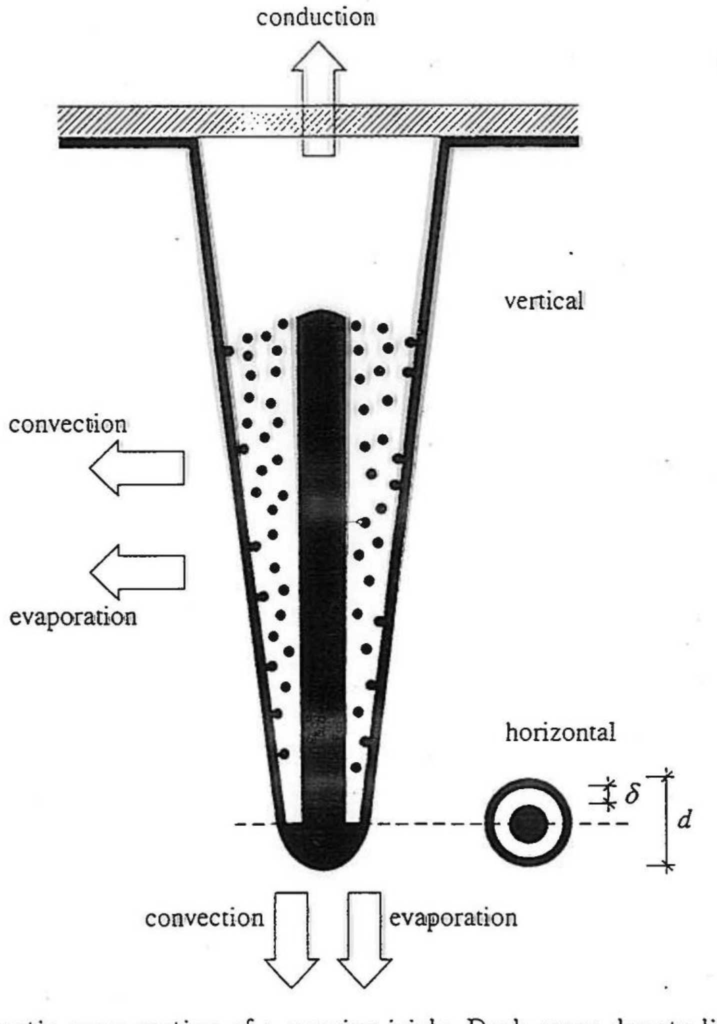

Figure 11. Schematic cross-section of a growing icicle. Dark areas denote liquid water and white areas denote ice. Dimensions are exaggerated.

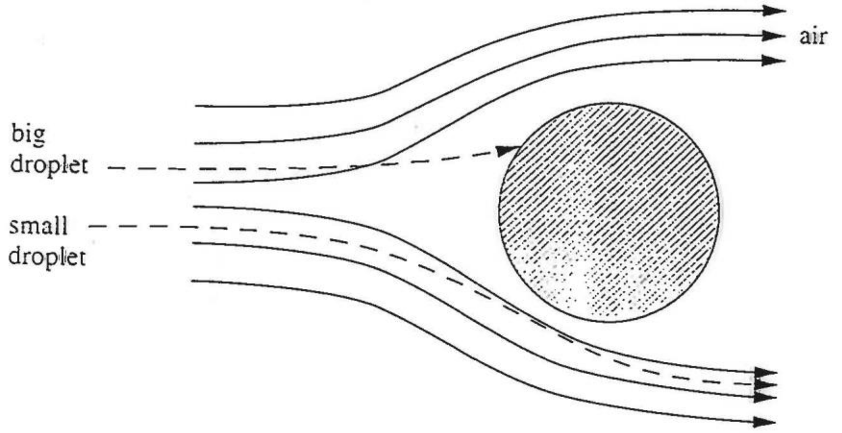

Figure 5. Air streamlines and droplet trajectories around a cylindrical object.

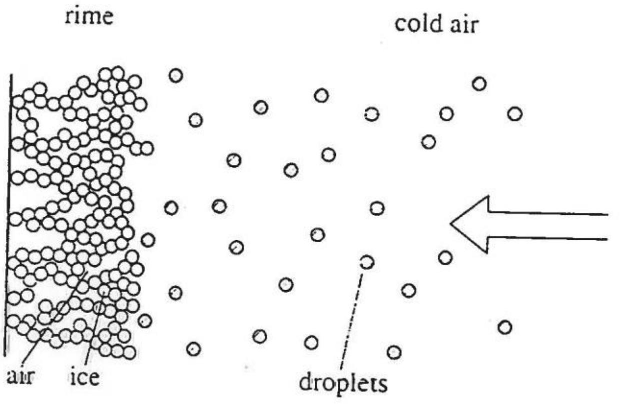

Figure 6. Growth of rime ice (dry growth).

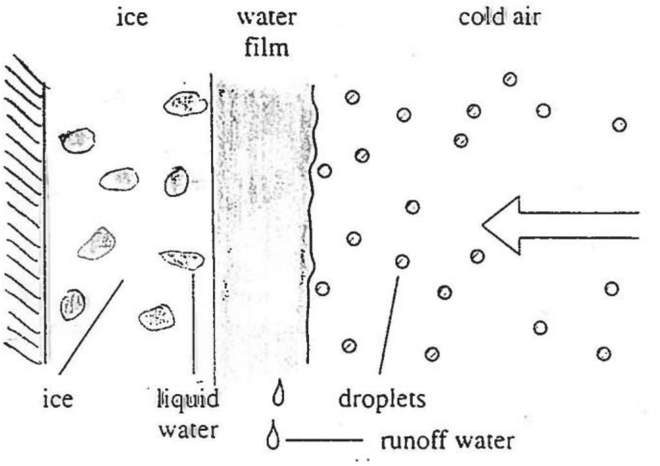

Figure 7. Growth of glaze ice (wet growth).

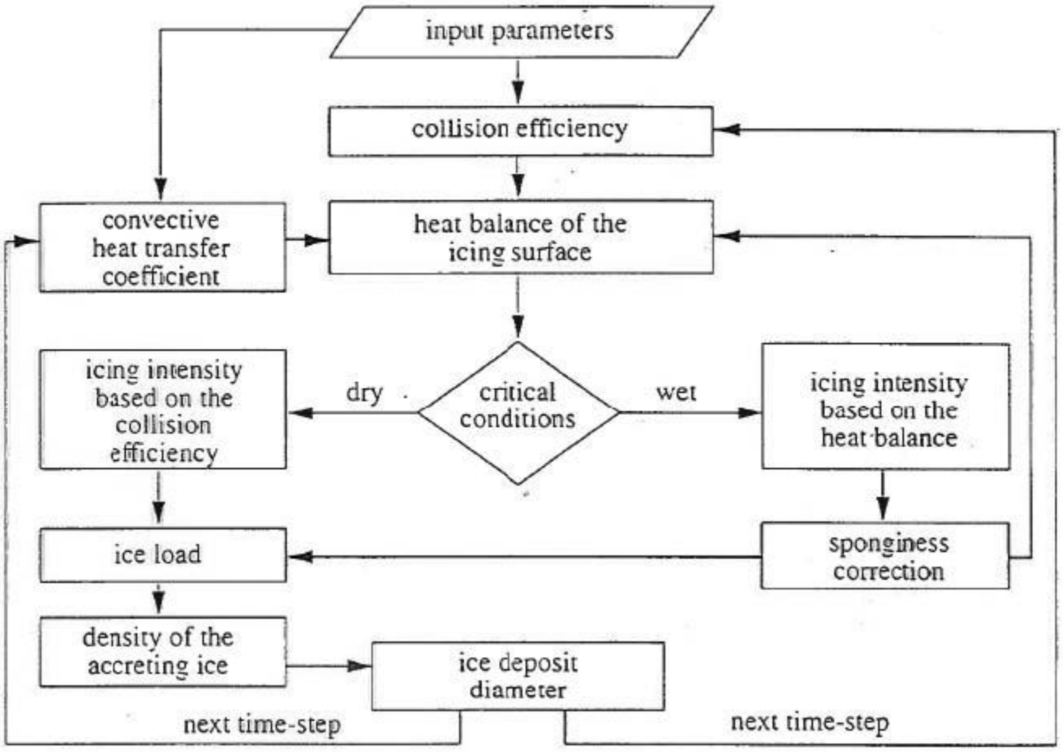

Figure 10. Simplified block-diagram of a numerical icing model.

$$\frac{dM}{dt} = \alpha_1 \alpha_2 \alpha_3 wvA$$

A – pindala, v – kiirus (⊥) M – mass , w – massi konsentratsioon α_1, α_2, α_3 ~[0,1] α_1 – „osakeste“ põrkumine

α_2 – „osakeste“ kleepumine α_3 – jäätumine (akretsioon), $\alpha_3 = 1$ – kuiv

$\alpha_3 < 1$ – märg

Näide: Kiirrong tunnelis

1 Üldskeem

2 Probleemi geomeetria

3 Katseseade

4 Mudel – survelaine amplituud sõltuvana tunneli ja rongi ristlõike pindaladest, rongi kiirusest, Machi arvust ja õhu tihedusest

Viide:

Howe M.S. et al. Theoretical and experimental investigation of the compression wave generated by a train entering a tunnel with a flared portal. J. Fluid Mech., 2000, 425, 111-132.

J. Fluid Mech. (2000), vol. 425, pp. 111–132. Printed in the United Kingdom

Theoretical and experimental investigation of the compression wave generated by a train entering a tunnel with a flared portal

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(Received 14 February 2000 and in revised form 10 July 2000)

The compression wave generated by a high-speed train entering a tunnel is studied theoretically and experimentally. It is shown that the pressure rise across the wavefront is given approximately by

$$\frac{\rho_0 U^2}{1-M^2}\frac{\mathscr{A}_0}{\mathscr{A}}\left(1+\frac{\mathscr{A}_0}{\mathscr{A}}\right),$$

where ρ_0, U, M, $\mathscr{A}_0$ and $\mathscr{A}$ respectively denote the mean air density, train speed, train Mach number, and the cross-sectional areas of the train and the uniform section of the tunnel. A monopole source representing the displacement of air by the train is

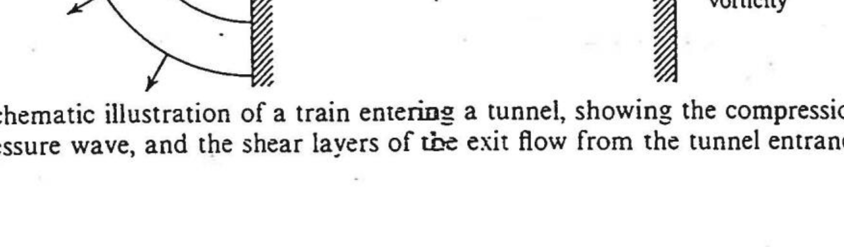


Figure 1. Schematic illustration of a train entering a tunnel, showing the compression wave, the micro-pressure wave, and the shear layers of the exit flow from the tunnel entrance portal.

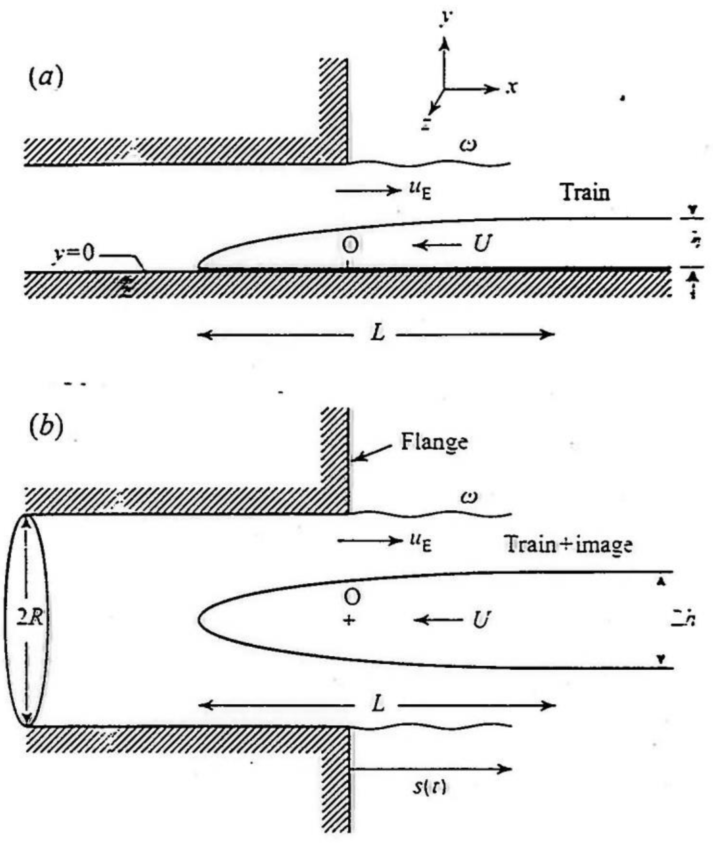


FIGURE 2. (a) Train entering tunnel. (b) Dynamically equivalent configuration consisting of the train and its image in the ground plane entering a flanged duct formed by the reflection of the tunnel walls in the ground plane.

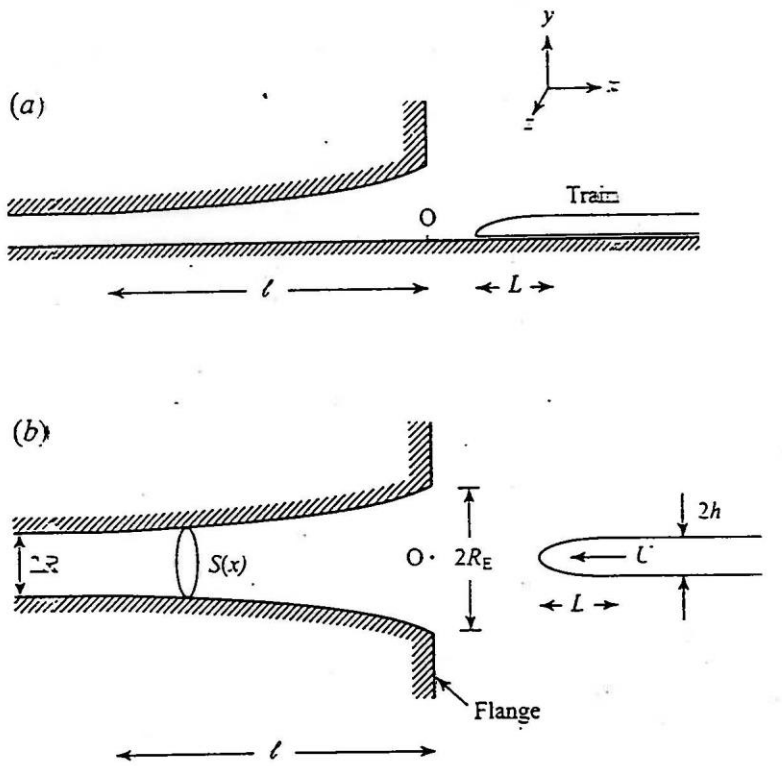
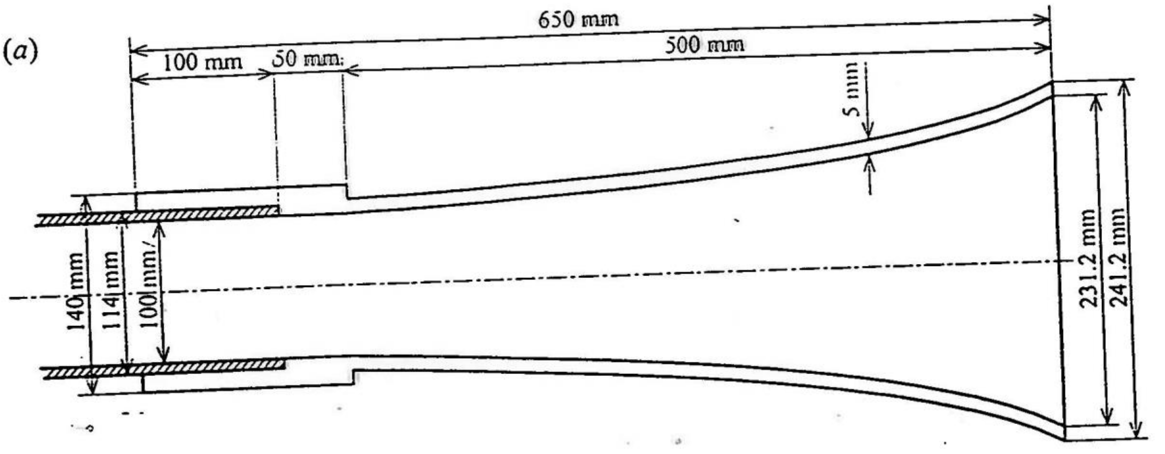


FIGURE 5. (a) Train entering a tunnel with a flared portal of length ℓ: (b) axisymmetric flared portal with an infinite flange.

(a)



(b)

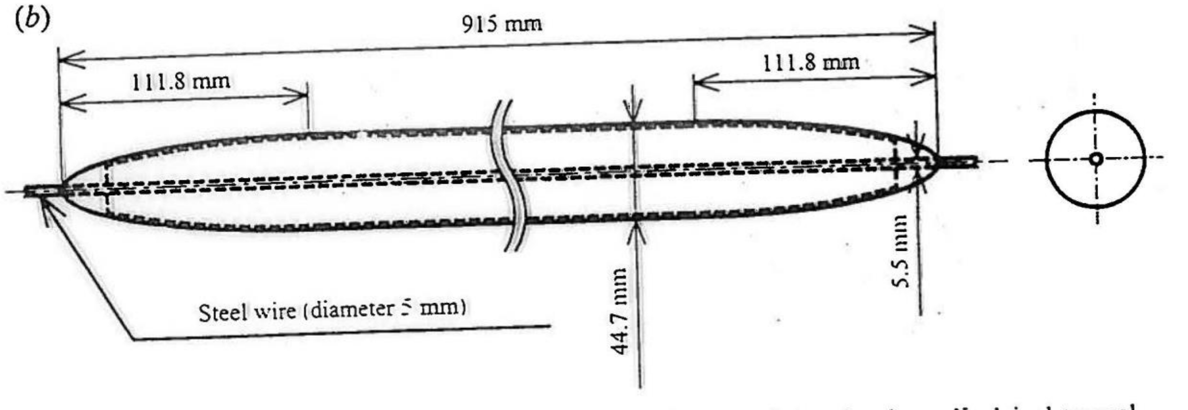


FIGURE 10. (a) The optimally flared portal fitted to the end of the circular cylindrical tunnel. (b) Model train with ellipsoidal nose and tail.

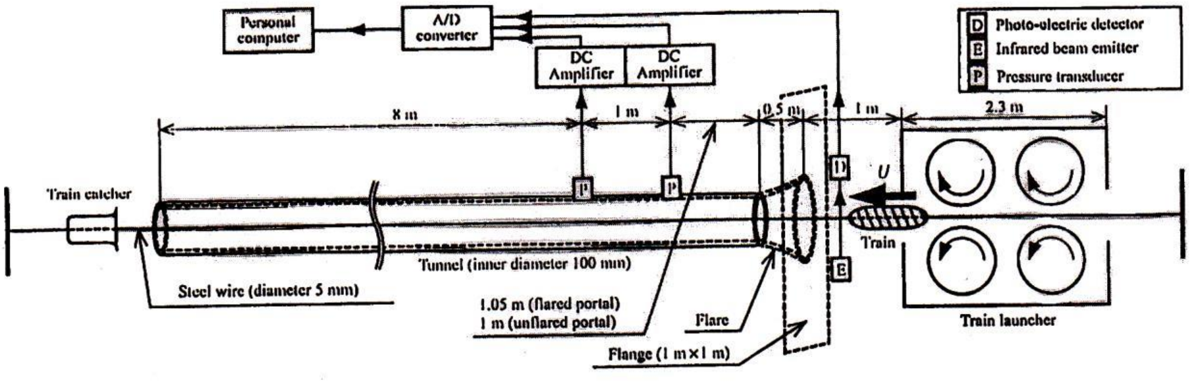


FIGURE 8. Schematic of the experimental apparatus.

Compression wave generated by a train entering a tunnel

Näide: iseorganiseeritus

1. Konvektsiooni mustrid
2. Minimagnetite käitumine
3. Liblikate tiivamustrid
4. Õiesüdamikud
5. M. Escheri transformatsioonid

Viiteid:

P.Ball. The self-made tapestry. Pattern formation in nature. Oxford University Press, Oxford, 1999.

vt. Loeng 11

Näide: muusika

1. Kuulmispiirkond
2. Müraspektrid
3. Logistilise kujutise “muusika”
4. Helindite spektrid
5. Fraktalanalüüs
6. Linnulaul
7. Näide – etüüdid Hénoni atraktori teemal

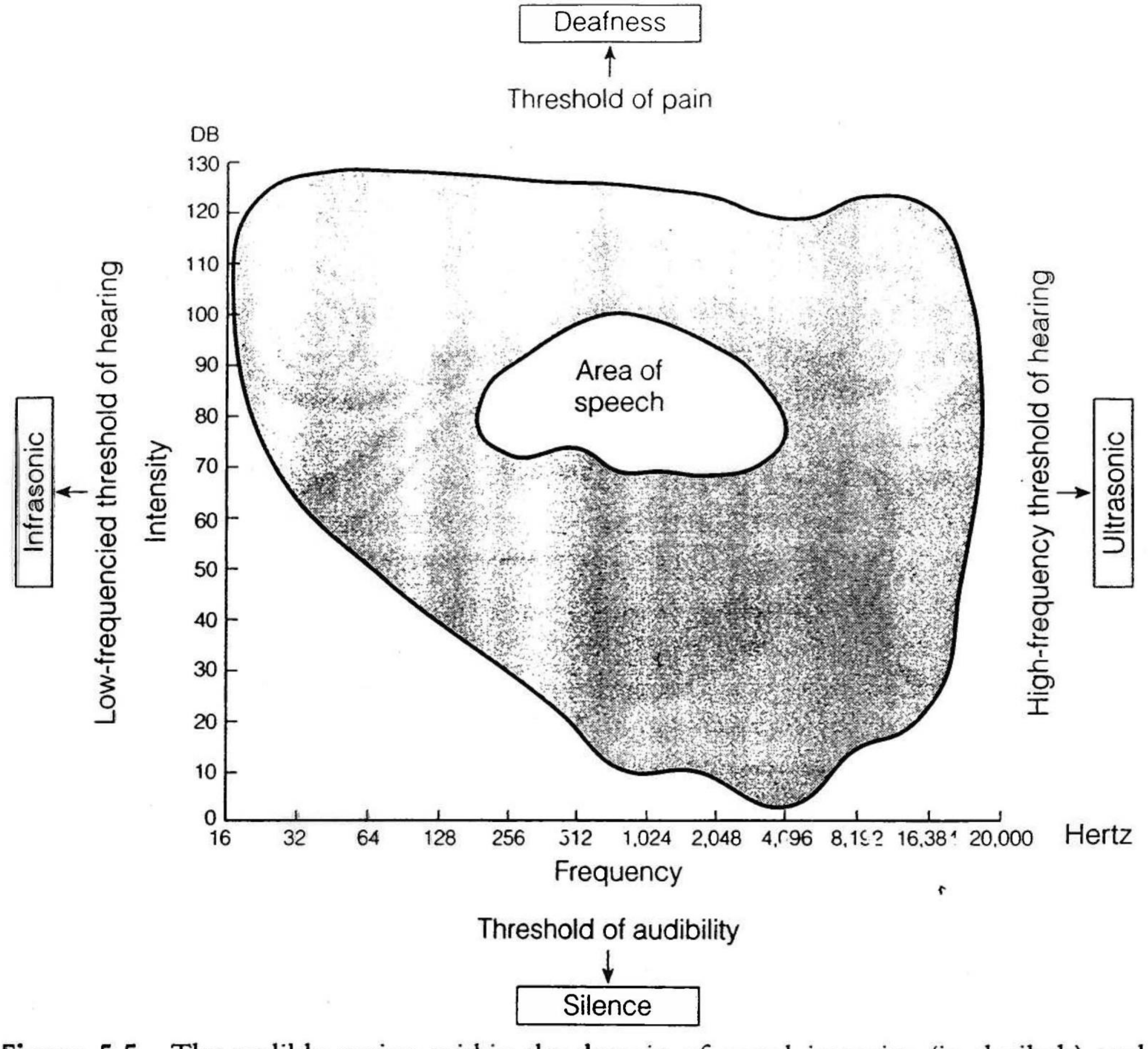


Figure 5.5 The audible region within the domain of sound intensity (in decibels) and frequency (measured in hertz).

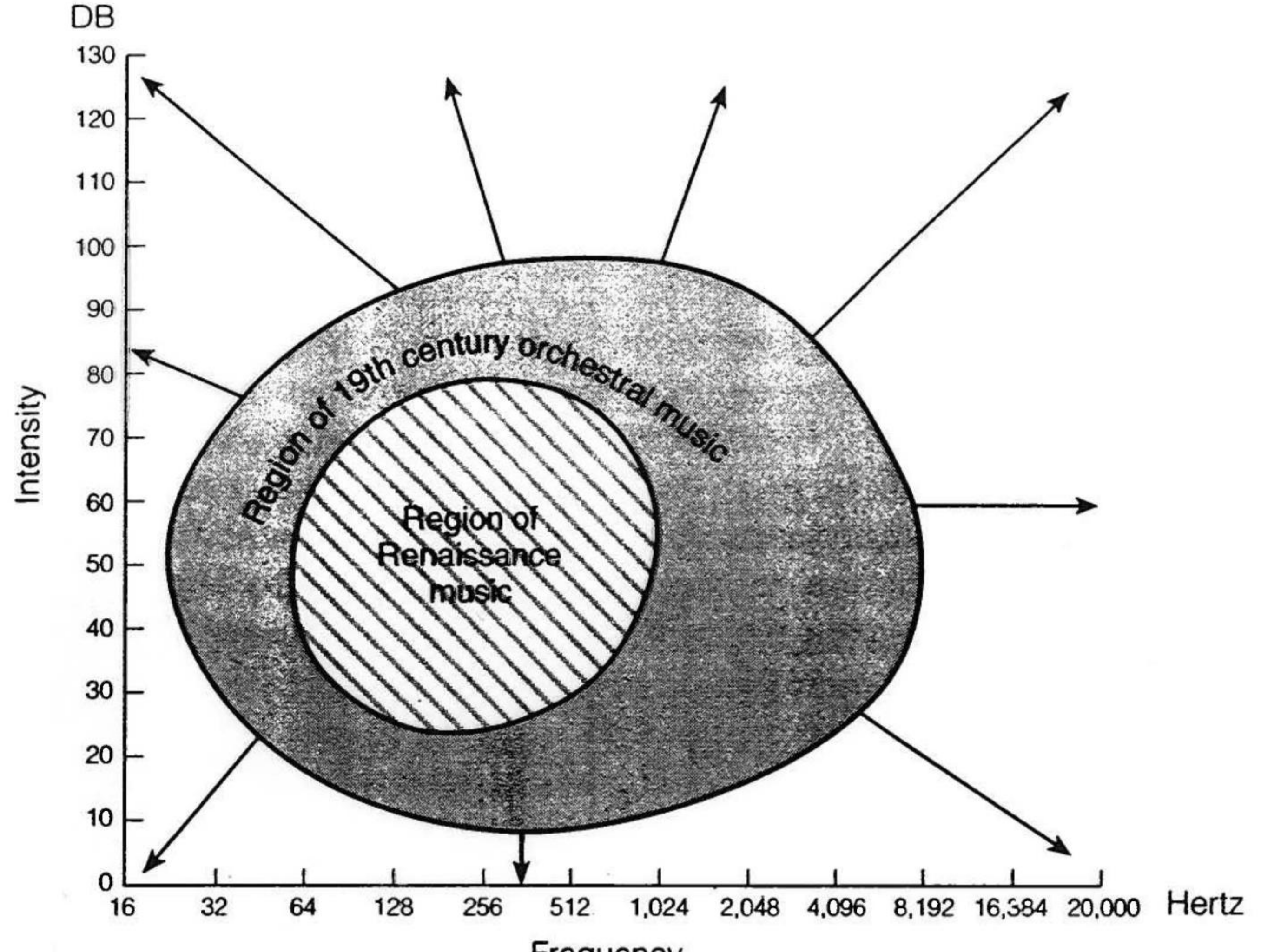


Figure 5.7 The ranges of sound intensities and frequencies employed in Western music have evolved to fill a greater fraction of the whole audible range. Here the domain of Renaissance music is compared with that of nineteenth-century orchestral music. Modern electronic music can, in principle, be designed to fill the entire audible domain of Figure 5.5.

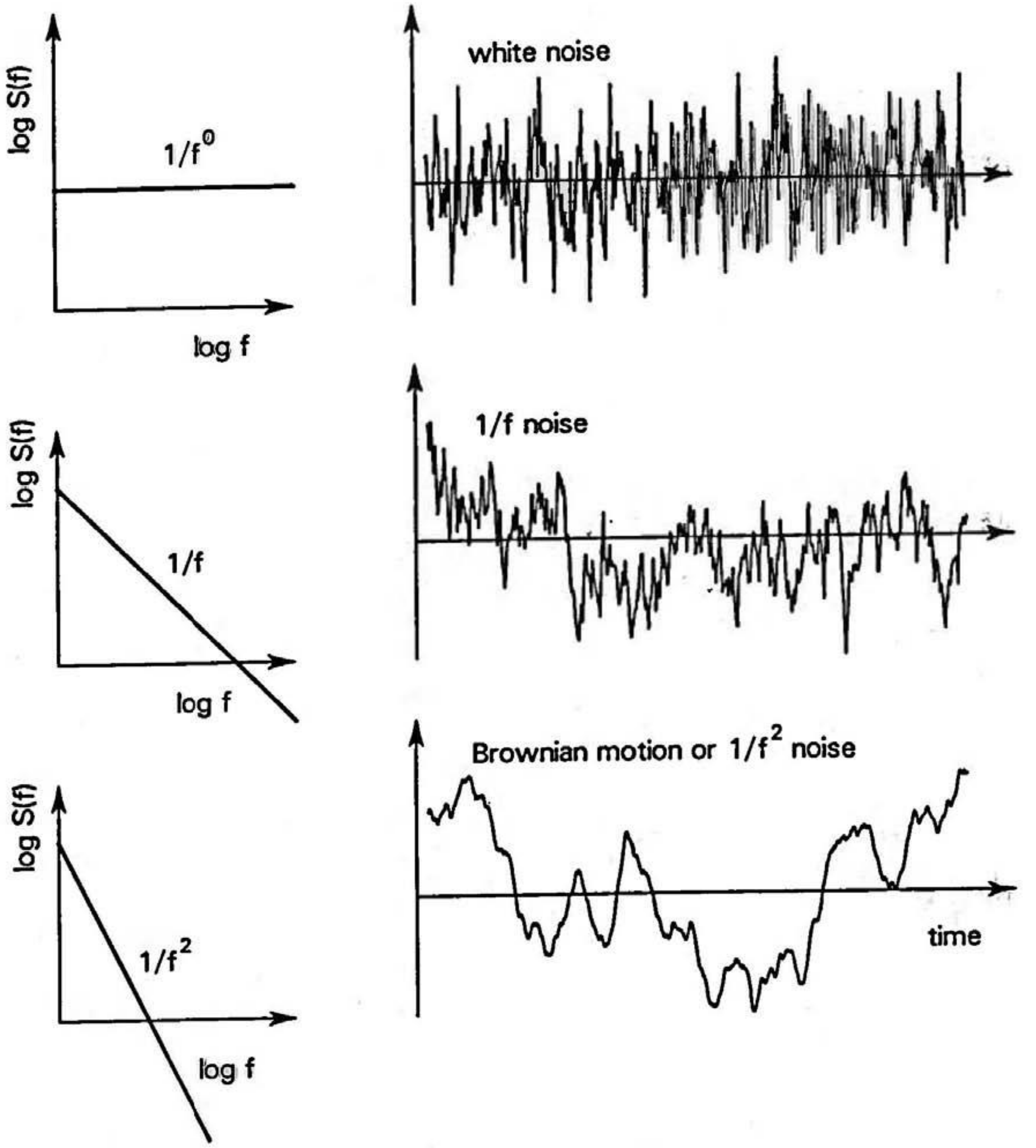


Fig. 1.9: Samples of typical "noises", $V(t)$, the random variations of a quantity in time.
a. White noise, the most random.
b. $\frac{1}{f}$-noise, an intermediate but very commonly found type of fluctuation in nature, its origin is, as yet, a mystery.
c. Brownian motion or a random walk.
To the left of each sample is a graphical representation of the spectral density, $S_V(f)$, a measurement characterizing the time correlations in the noise.

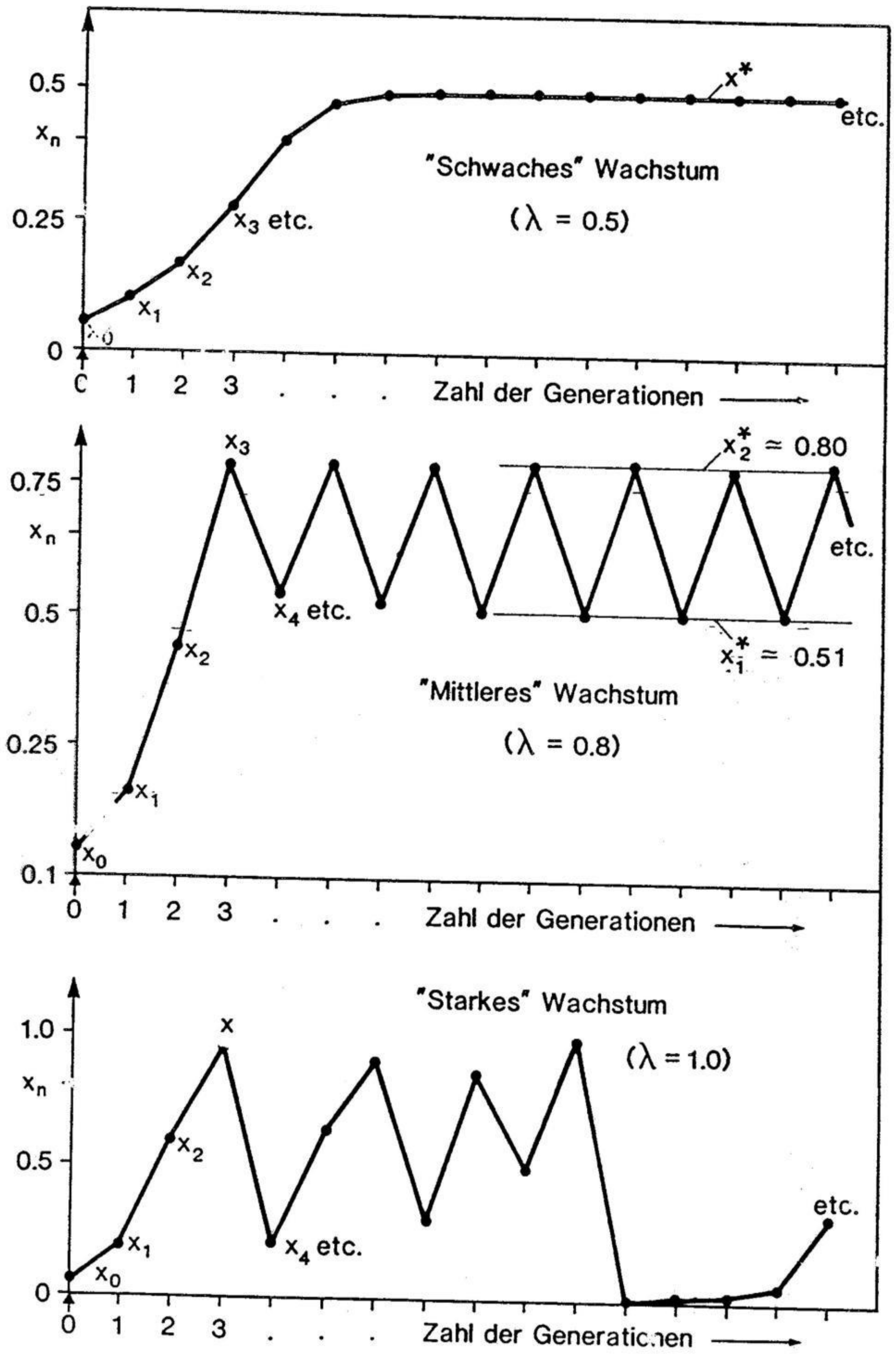


Abbildung 2.1: Das Iterationsschema der Verhulst-Dynamik bei verschiedenen Werten des Wachstumsparameters λ: Schwaches Wachstum ($\lambda = 0.5$) mit einem Attraktor, mittleres Wachstum ($\lambda = 0.8$) mit 2 Attraktoren und starkes Wachstum ($\lambda = 1$) mit chaotischem Verhalten der Populationen

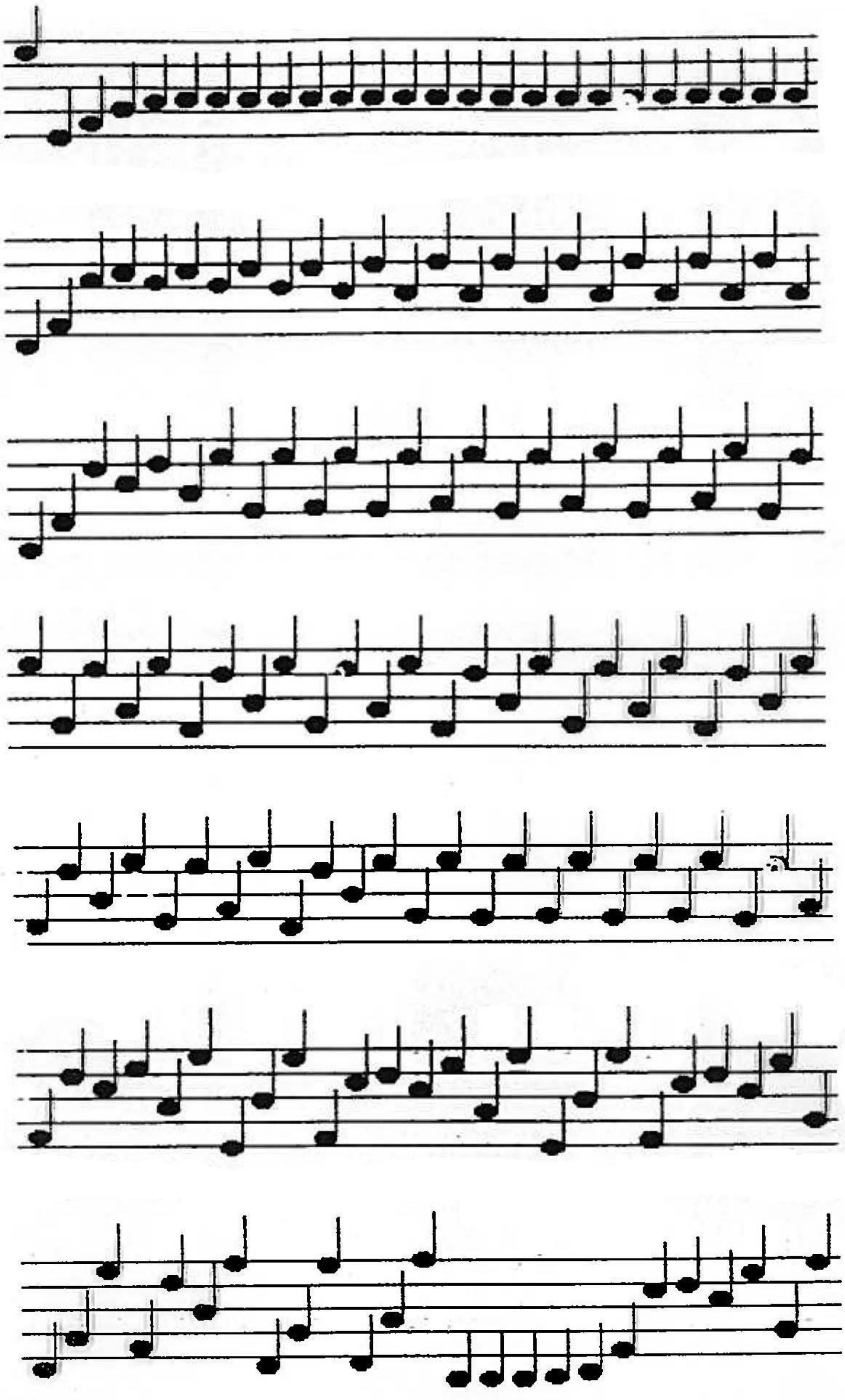


Figure 62 Schematic representation of the iterates of a logistic mapping $x \rightarrow kx(1-x)$ in 'musical' notation. The height of the 'notes' represents the value of x, and the 'stave' is drawn arbitrarily. The constant k is (top to bottom) *2, 3.2, 3.5, 3.56, 3.6, 3.8, 4.0. As k increases, the music becomes more random in quality.*

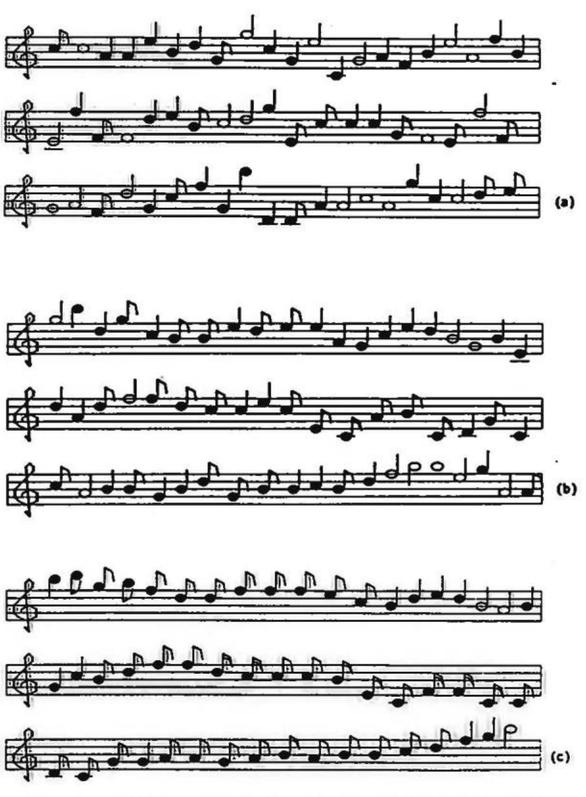



Fig. 1.11: Samples of stochastically composed fractal music based on the different types of noises shown in Figure 1.9 . a. "white" music is too random. b. "$\frac{1}{f}$"-music is the closest to actual music (and most pleasing). c. "Brown" or $\frac{1}{f^2}$. Music is too correlated.

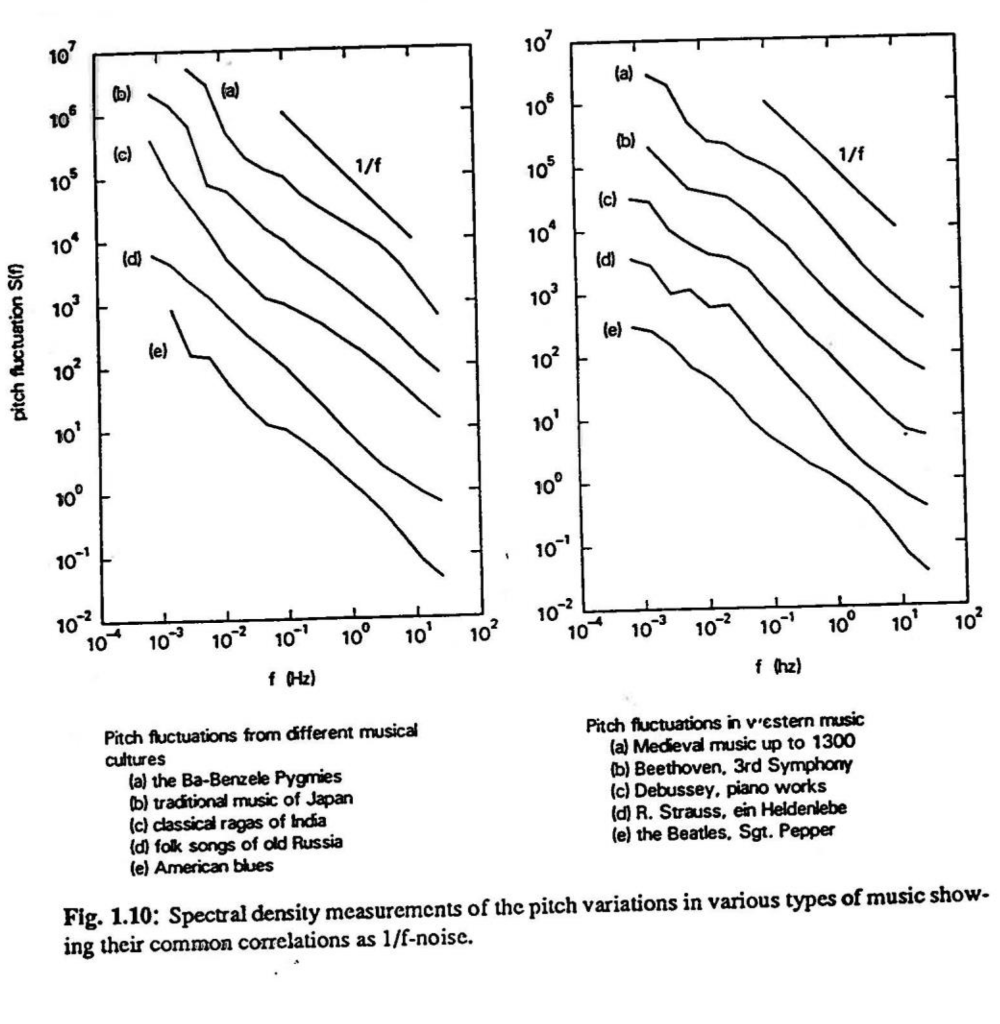


Fig. 1.10: Spectral density measurements of the pitch variations in various types of music showing their common correlations as 1/f-noise.

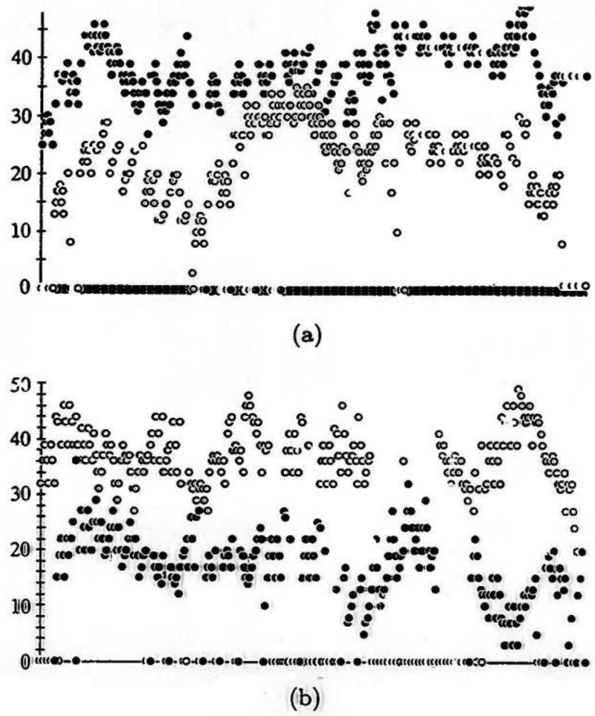


Figure 3. Digitized scores of Bach's (a) *Invention no. 1*; (b) *Invention no. 10*. o, right hand; •, left hand.

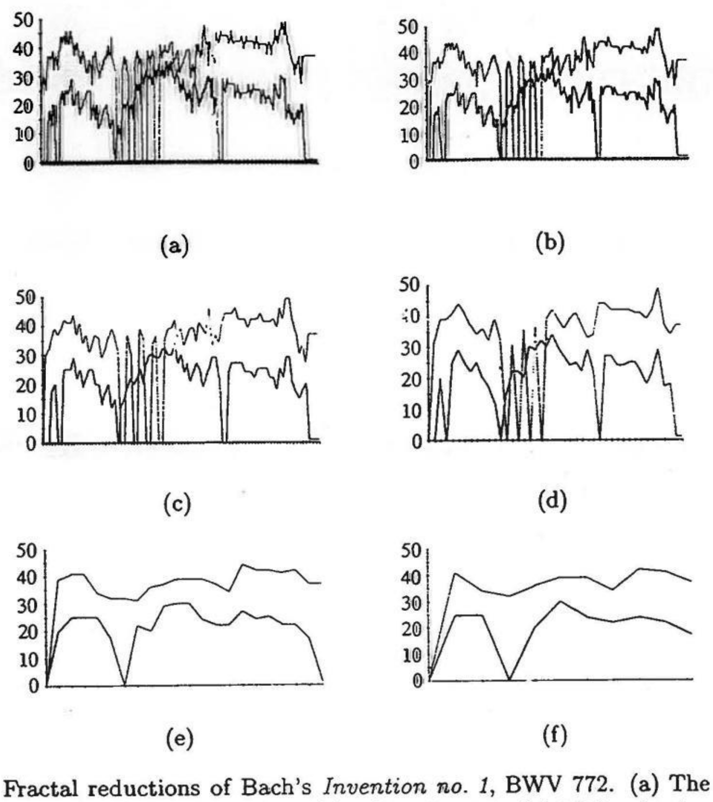


Figure 4. Fractal reductions of Bach's *Invention no. 1*, BWV 772. (a) The original; (b) 1/2 reduction; (c) 1/4 reduction; (d) 1/8 reduction; (e) 1/16 reduction; (f) 1/32 reduction of the score.

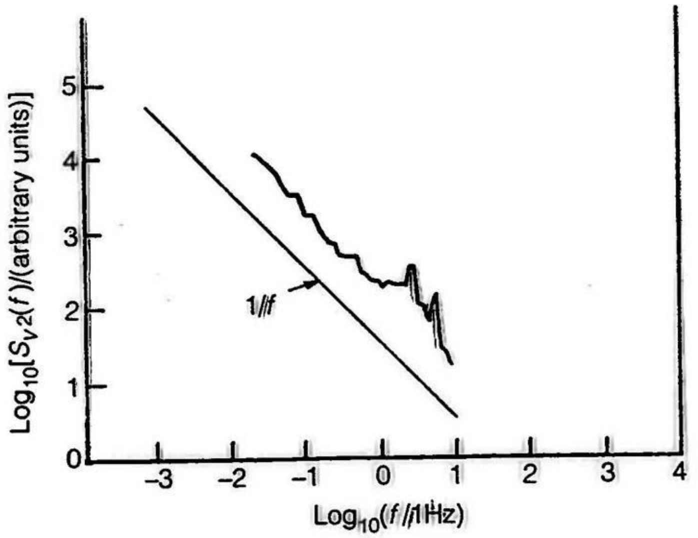


Figure 5.12 The spectral density of audio power ('loudness') versus sound frequency, *f*, in logarithmic units for Bach's First Brandenburg Concerto, measured by Richard Voss and John Clarke.

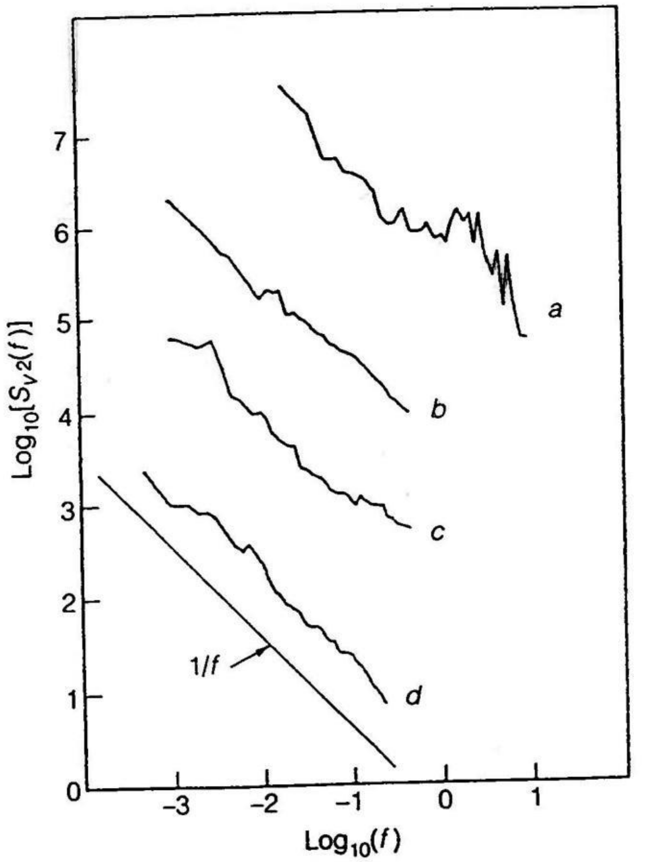


Figure 5.13 Loudness variations with frequency, *f*, for a range of structured sounds: (a) Scott Joplin Piano Rags; (b) classical music radio station; (c) rock music radio station; (d) news and talk radio station; as measured by Voss and Clarke.

Näide: ämblikuvõrk

“mitmekihiline” niit: kaitsekiht – nahk – tuum material: proteiinil

põhinevad amiinohapped valmistamine: madal temperatuur

madal energiakulu

tugevusomadused: vt. andmed

Viited:

ämblikuvõrk:

- Vollrath F. and Knight D.P. Liquid crystalline spinning of spider silk. Nature, 2001, 410, 541-548.
- Engelbrecht J. Challenges for tensile stresses. Proc. Estonian Acad. Sci. Engineering, 2002, 8, N 2, 134-142.

rippkatete arvutus:

Kulbach V. Investigation of prestressed cable structures at Tallinn Technical University. Proc. Estonian Acad. Sci. Engineering, 2002, 8, N 2, 68-83.

vt. Loeng 5

Näide: kortsutatud paber

1. Katse
2. Teooria:

- G.Gomper, Patterns of stress in crumpled paper. Nature, 1997, 386, 439-440.
- M. Ben Amar and J.Pomenn, Crumpled paper. Proc. Royal Soc. London, 1997, 453, 729-755.
- 3. Lahendusideed
- leida pingefunktsioon, mis minimiseerib energia;
- määrata kortsutatud pinna fraktaalsus

5. Fullereenimolekul, jalgpall

vt. Loeng 13

Näide: rakuautomaadid cellular automata

Rakuautomaat: elementide (rakkude) kogum,
mille omaduste muutuseks rakendatakse
teatud reeglite kogum

Ruum: diskreetne (1D, 2D, 3D)

Aeg: diskreetne

Olulised viited:

1. Stephen Wolfram. A New Kind of Science. Wolfram Media, Champaigne (Illinois), 2002 (S.Wolfram is the author of Mathematica, see: www.stephenwolfram.com
2. Daniel T.Kaplan ao. Nonlinear Dynamics in Cardiac Conduction. In A.S.Perelson et al (eds.), Nonlinearity in Biology and Medicine. Elsevier, New York, 1988, 19-48.

Joonised:

1. Näited kristallstruktuuridest
2. Rakuautomaatide idee S.Wolframi näidetes
3. Erutusfrondi levi südamelihases D.Kaplani jt. näidetes.

vt. Loeng 3 vt. Loeng 14

Näide: pinna jaotamine osadeks ja kristallstruktuurid

1. Kristallstruktuurid
2. Penrose'i struktuurid
3. M.Escher'i pinna jaotused, nende seos kristallstruktuuridega.

Viiteid:

1. D.Schattschneider. Visions of Symmetry. Freeman Co, New York, 1990.

vt. Loeng 5

Terviklus/complexity

1. T/C süsteemid koosnevad paljudest seostatud osadest, mis võivad interakteeruda
2. T/C süsteemides võib esineda kriitilisi olukordi, kus väikesed välistõuked võivad viia süsteemi tasakaalust välja ja uue oleku tekkele
3. T/C süsteemides võib esineda iseorganiseerumist, mis algab lokaalsetest muutustes kuid süsteemi uue oleku omadused on globaalse iseloomuga
4. T/C süsteemid on avatud ja adaptiivsed ning tihti määratud lihtsate reeglitega
5. Muutused T/C süsteemides tekivad kitsas parameetrite vahemikus, nn kaose piiril

   ... – kord – T/C – kaos – T/C – kord – ....
6. T/C süsteemid on mittelineaarsed

Lihtsate mudelite käitumine?

- universaalsus – ?
- ennustatavus – ?
- bifurkatsioonid – ?
- sümmeetria rikkumine – ?

Lihtsaid mudeleid

- liivakuhik
- pendlite süsteem
- metsatulekahjud
- maavärinate blokkmudel
- maastike kujunemine

ERA-NET COMPLEXITY

Stronger focus on the field of Complexity

- Nine European Research Councils and Ministries (Belgium, Denmark, Estonia, Greece, Ireland, The Netherlands, Portugal, Spain, and U.K.) has initiated a cooperation ”Complexity-NET”
- The objective is to examine the need and opportunities for a better coordination of the European research activities within complex systems and processes and related technologies
- The cooperation originated in continuation of the decision by the European Commission Committee CREST for Science and Technological Research to select complexity and complex systems as one of five pilot areas for programme coordinating activities
- The cooperation is financed by the European Commission under the ERA-NET initiative

Complexity research

- The world does not consist of simple linear relations but show generally features that originate entirely from inherent nonlinearities
- The world develops and adapt dynamically, often driven far away from simple equilibrium
- Complexity research has its origin in the natural sciences of mathematics, physics, chemistry, biology, and computer science, but has now spread into the economic and social sciences
- Complexity research is holistic and a multi-disciplinary field covering research in nonlinear dynamical systems, systems out of equilibrium, control theory, adaptive and self-organising systems and complex dynamical networks of interacting units
- The systems investigated differs widely in character, size and time scale

Increasing demand for Complexity research and technologies

- Production industry (food, materials, chemical industry etc.) needs more effective analysis, decision support and process control tools;
- Bio-sector needs the development of new mathematical models to analyse complex organisms;
- Better energy resources and environment requires improved analyses of the dynamics of wind, water and other fluid systems;
- Modern information and communication systems depend on the development of new signal and image processing tools;
- The application of new nonlinear and complex methods in economical and financial analysts is rapidly increasing;
- Modelling of social systems, agent-based systems, proactivity.

Complexity-NET

The European Complexity network on the programme level

Complexity – the emerging science and technology

Complexity and complex systems is an emergent and rapidly growing research field with a large technological potential. Europe has fostered a scientific excellence in the interdisciplinary field of complexity with extensive collaborations across Europe and abroad. National funding organisations are aware of this development and several countries have initiated strategic programmes within the field.

Based on the need to put stronger focus on the field of Complexity and to further the large growth potential within this field, nine European Research Councils and Ministries (Belgium, Denmark, Estonia, Greece, Ireland, The Netherlands, Portugal, Spain, and U.K.) initiated August 1, 2004, a cooperation ”Complexity-NET” in form of a Specific Support Action with the objective to establish a decision fundament for coordinating nationally strategically planned research activities within the field of complexity. The Specific Support Action was financed by the European Commission under the ERA-NET initiative.

In the Specific Support Action information and experiences has been exchanged regarding main activities and programmes supported in the participating countries, and the instruments and general procedures used in the handling of applications. The consortium has identified national research and training programs with overlap to complexity and established contacts to major complexity research groups funded by these national programs and EU networks, and in workshops worked out the content of an ERA-NET proposal, including a dissemination plan. Further, the consortium has clarified the possible economic base and evaluation and handling processes, and the consortium has discussed the best form of a management framework. Collection of information and the following analysis has been carried out by a steering committee for

Complexity-NET with representatives from the participating Research Councils and Ministries.

The initial work has shown a significant need for better coordination within complexity and complex systems on the program level and very good opportunities to exploit the great growth potential there is within complexity research. Our ambition is the formation of a nationally coordinated European setting (e.g. ERA-NET) on complexity with the purpose to further common use of experimental facilities, enhance international training and mobility, support international scientific communication (workshops etc.), promote public dialogue and awareness, and catalyze innovation in the European complexity area.

The coordinated action proposed here is the work needed in order to establish this setting. To this end the consortium shall continue their collection and exchange of information on strategically funded complexity-related national research and research-training activities, procedures and best practices, and analyse and discuss the material to a level where a joint action plan can be formulated and agreed upon, leading eventually to transnational research activities.

Complexity – a rapidly growing field of research and development

The globalisation and the ongoing transfer to an increased knowledge based society has resulted in an increasing demand for more effective analysis, decision support and process control tools to the production industry (food, materials, chemicals and drugs etc.), an increasing demand for the development of new mathematical models to analyse complex organisms in the bio-sector and to analyse the dynamics of wind and water systems, and an increasing demand for the development of new signal and image processing tools, including tools for use in modern information and communication systems. The understanding of such complex systems and the development of new models, methods, and tools to improve and control the processes based on this knowledge is central for surviving in the highly competitive global market of today.

Moreover new complex methods are increasingly being required for future social, economical and financial analyses. Processes involving many people in interaction are generally complex, and new fields of complexity have emerged to undertake research of such complex processes. One of these is econophysics, dealing with the complex dynamics in economy and in the financial markets, accepting the now ample evidence of non-trivial distributions of fluctuations in price and in exchange rates. The understanding of complexity in economics has provided the field with new technical indicators, with new insight in risk and volatility, and new measures for putting together a portfolio of stocks.

The basic research and development behind the above mentioned methods and tools has grown within the last decades to a field called Complexity, indicating the acceptance of a world that does not consist of simple linear relations but rather show features that originate entirely from inherent nonlinearities, and the acceptance of a world that develops and adapt dynamically, often driven far away from simple equilibrium. A rapidly increasing number of new measuring devices and software technologies are being developed by innovative enterprises that have opened new markets, introducing the novel and exciting methods derived from complexity research.

Some complex systems evolve in a deterministic way, but their long time evolution may not be predictable from the original conditions. Understanding the concept of deterministic chaos and the complex patterns that are formed by nonlinearities has been central steps in the scientific development. Moreover, driven out of equilibrium, complex systems generate fractal structures and scale invariant distributions, and entirely new types of phase transitions have been discovered with a potentially great impact on future technologies and new material designs. The observations have given rise to new concepts such as multifractality and self-organised criticality, and entirely new non-equlibrium statistical methods have been introduced to understand the variety of complex phenomena encountered.

Complexity research has its origin in the natural sciences of mathematics, physics, chemistry, biology, and computer science, but has now spread into the economic and social sciences. By nature it is holistic and a multi-disciplinary field covering research in nonlinear dynamical systems, systems out of equilibrium, control theory, adaptive and self-organising systems and complex dynamical networks of interacting units. The systems investigated differs widely in character, size and time scale, from the complex process of a power station to the spreading behaviour of a micro-organism, from the fast reactions in a chemical reactor to the complex evolution of our geography and universe, from fluctuations in the sea level to fluctuations in prices and exchange rates.

Complexity is ubiquitous, producing some of the most intriguing patterns and forms. Scientific research has traditionally examined simplified systems composed of a small number of elements in an attempt to establish principles on which they operate and, where possible, formulate a mathematical model capable of reproducing the behaviour of the original system. However, a wide variety of systems with many interacting components show remarkable properties of self-organisation when driven out of equilibrium. In such cases coherent structures emerge from the system as a whole, which cannot be explained by the behaviour of the single elements. Such systems, consisting of a large number of interactive elements which may organised on many scales, are known as complex systems.

The intriguing thing about complex systems is that they include examples from almost all aspects of the real and conceptual world, where interactions are associated with exchange of energy or information. Among such examples is the metabolic and signalling network in a living cell of a biological organism, growth of bacterial colonies, spread of diseases, the biocomplex evolution of life encountered in ecosystems (including processes like natural selection), earthquakes, forest fires, and the evolution in financial markets and social networks. Certain chemical reactions and the transport of light, sound, fluids, and even cars or people generate complex phenomena like turbulence and emerging traffic jams and crowd behaviour.

In parallel to the development of a theoretical framework and the numerous experimental discoveries of complex phenomena, a wide variety of computer programming and modelling techniques has been developed. This and the advent of powerful computers have empowered researchers to study in greater detail the emergence and development of complex systems and phenomena. Computers with massive data-handling capacity are constantly being updated to compute ocean and weather conditions. New and better neural network algorithms are being built and refined to imitate the learning process of our brains and adaptive robots based on artificial intelligence are constructed to solve complex problems or control complex systems. Bioinformatic programmes are developed to analyse genomic information from DNA chips in order to reveal the genetic secrets behind our cellular functions.

Complexity is one of the fastest growing research fields in the world. Seen in the light of the explosive growth in number of scientific articles and new journals with focus on this area as well as the increasing number of small and medium sized enterprises developing new science based tools originating from the results of complexity research, the field of complexity research and technology is today a very attractive growth area. A simple search on the internet shows that complexity, complex systems, complexity research or complexity science results in millions of hits in line with a search on nanoscience or nanotechnology.

Especially in the U.S.A., complexity research and research training has created one of the most promising growth bases for emerging technologies capable of dealing with the increasingly complex tasks of the knowledge-based society. A strong strategic effort has been formulated and implemented in U.S.A. in order to benefit from the relatively low-cost value-creating process taking place in the field of complexity. As a consequence, many of the best young as well as experienced scientists from Europe are attracted to U.S. universities and enterprises to carry out complexity research and to develop new businesses in U.S. However, Europe cannot afford to loose terrain, and effective steps must be taken immediately to improve the European situation. Coordinated complexity research and research training efforts and the development of novel and more effective solutions to the large class of complex systems and processes characterising the technological frontline is not only necessary but also crucial in order to stay competitive in a highly globalised market.

Complexity – the need for coordination

To repair the very threatening situation of being left behind in an expanding market, the Complexity-NET cooperation intends to improve the stimulation of complexity research and innovation through a dedicated strategic plan where coordination of funding in Europe to complexity research and research training is a central element in order to succeed. To this end European Research Ministers have already acknowledged the importance of the opening of national programmes as a key step forward in the construction of the European Research Area. Also, focus has been brought to the subject of complexity through CREST who has supported the ERA-NET initiative by pointing out complexity as one of the top five subjects.

The ERA-NET on complexity, called the Complexity-NET, was initiated by 9 European Research Councils and Ministries (Belgium, Denmark, Estonia, Greece, Ireland, The Netherlands, Portugal, Spain, and U.K.) in form of a Specific Support Action August 1, 2004. Through an analysis of national research funding activities and funding procedures, it has been possible to define and specify a Coordinated Action on complexity, which can set the scene for a strategic funding of complexity research and research training on the European level through a joint action plan, including the opening of national programmes and the possibility of joint research or research training programmes. One of the steps in the action plan towards a joint European complexity programme is the ongoing recruitment of new partners, including new member and candidate countries.

The vision of the Complexity-NET is the creation of strategic activities that can further common use of experimental facilities, enhance European research training and mobility and scientific communication (workshops etc.), promote public dialogue and catalyse innovation throughout Europe. In EU, where the population percentage of researchers is 10 % smaller than the U.S. percentage and the percentage of highly cited articles are about half of the U.S percentage, coordination seems to be highly needed. A comparison between EU and U.S. funding shows that since 1995 public R&D investments have on the average increased four times faster in U.S., and private R&D investments have in average increased twice as fast in U.S. This further underlines the strong urgency to coordinate funding efforts.

Related European activities

Within the last ten years, the science of complexity has become one of the newly emerging technologies at both the national and the European level. Some EU member states have begun specific national research programmes or included complexity in more general initiatives. One of the initiatives has been EXYSTENCE, the complex systems network of excellence that was funded by the FP6 IST Programme on Future and Emerging Technologies. Another initiative is the FP6 new and emerging science and technology (NEST) initiative on ‘Tackling complexity in science’. Yet another is the COST action “Risk”, which brings together scientists applying complexity methods to quantitatively analyse risks in, e.g., financial markets. The Complexity-NET consortium is in contact with all these initiatives, which all provide very helpful steps in the process of coordinating national research and research-training programmes involving complexity researchers.

The European Science Foundation (ESF) formed by the European Research Councils has gained valuable experience from their EuroCore initiative and other ERA-NET initiatives. In connection to Complexity-NET they have taken concrete steps to be involved and to act as an office of knowledge exchange.

The European Physical Society has formed a Division on Statistical and Nonlinear Physics (EPS-SNP) with high focus on complexity, helping with coordination and communication on the more practical level. EPS-SNP may be an important contributor to the development of the Complexity-NET by ensuring an effective and broad contact to the European complexity research.

The dialogue with a number of European committees provides important contributions to the development of the Complexity-NET. Among these committees are EUROHORC (European Heads of Research Councils) and EUPRO (European Union of Physics Research Organisations).