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Analytical methods of musical composition based on fractal theory

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Abstract: This study explores how the fundamental principles of fractal theory can be applied to the creation of musical compositions. The research focuses on the mathematical modeling of musical structures through self-similarity, iterative constructions, and the branching characteristics of fractal geometry. In particular, it analyzes musical structures generated using fractal models such as L-systems, IFS (Iterated Function Systems), and Brownian motion.
Keywords: Music, fractal, L-systems, IFS (Iterated Function Systems), Brownian Motion

Fraktal nazariyasiga asoslangan musiqa kompozitsiyasining tahliliy usullari

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Annotatsiya: Ushbu ishda fraktal nazariyasining asosiy tamoyillari musiqa kompozitsiyasi yaratishda qanday qo‘llanilishi mumkinligi yoritilgan. Tadqiqotda o‘z-o‘ziga o‘xshashlik (self-similarity), iteratsiya asosida hosil qilinadigan tuzilmalar va fraktal geometriyaning tarmoqlanuvchi xususiyatlari orqali musiqa shaklini matematik modellashtirish masalasi ko‘rib chiqilgan. Ayniqsa, L-tizimlar, IFS (Takrorlanuvchi funksiya tizimlari) va Brown harakati kabi fraktal modellar asosida yaratilgan musiqaviy tuzilmalar tahlil qilinadi.
Kalit so‘zlar: Musiqa, fraktal, L-tizimlar, IFS (Takrorlanuvchi funksiya tizimlari), Brown harakati

1. Kirish

Hozirgi kunda IT sohasining rivojlanishi o‘zining barcha sohalariga, jumladan, musiqa sohasiga ham chuqur kirib kelmoqda. Xususan, algoritmik kompozitsiya, sun’iy intellekt yordamida musiqa yaratish, raqamli ovoz tahlili, musiqiy tuzilmalarni vizualizatsiya qilish, MIDI (Musical Instrument Digital Interface) texnologiyalari asosida avtomatik ijro va tahrir qilish, shuningdek, virtual musiqiy asboblar orqali ijod qilish kabi yo‘nalishlar tobora ommalashib bormoqda. Bu esa musiqa yaratuvchilarga yangi imkoniyatlar eshigini ochib, an’anaviy uslublarni zamonaviy texnologiyalar bilan uyg‘unlashtirishga xizmat qilmoqda. Matematika va musiqa — ifoda shakllarining har xil bo‘lishiga qaramay — uzoq vaqtdan beri, Helmholtz aytganidek, “bir-biriga bog‘langan” deb tan olingan [1]. Bu bog‘liqlikni o‘rganishga oid ilk urinishlar odatda Pifagorga bog‘lanadi, biroq aslida bu ishlar ehtimol, uning ismi noma’lum bo‘lgan shogirdlari — Pifagorchilar tomonidan amalga oshirilgan bo‘lib, ular lyra cholg‘usida chalgan notalarga son qiymatlari berilgan [2].

2. Tadqiqot metodologiyasi

Adabiyotlar tahlili. Muallif Michael Edwardsning “Algoritmik kompozitsiya: Musiqada hisoblashli tafakkur” kitobida algoritmik kompozitsiya — ya’ni musiqani kompyuter algoritmlari asosida yaratish g‘oyasini chuqur tahlil qiladi. U musiqa yaratuvchilik faoliyatini matematik va L-tizimlar usuli orqali jarayonni qanday avtomatlashtirish mumkinligini ko‘rsatadi. Unda algoritmik yondashuv orqali musiqa kompozitsiyalari qanday shakllantirilishi, kognitiv va matematik modellar yordamida musiqaning strukturasi qanday aniqlanishi, hisoblashli tafakkur (computational thinking) usullari – masalan, logika, tsiklar, shartli operatorlar va funksiyalar – musiqiy g‘oyalarni qanday ishlab chiqishga xizmat qilishi, amaliy misollar orqali Python, Max/MSP yoki boshqa skript tili yordamida jonli yoki tayyorlangan (pre-composed) musiqalar qanday yaratilishi, musiqaning ritmi, tovushlarning birgalikdagi yoqimli uyg‘unligi (harmoniya), melodiyasi kompyuter yordamida qanday tahlil qilinishi va yangicha shakllar qanday generatsiya qilinishi muhokama qilingan.

Przemyslaw Prusinkiewicz ning “ L-tizimlar yordamida musiqiy protsidura yaratash” maqolasida L-tizim qoidasi, 0L-tizimlar usuli qo‘llanilgan bo‘lib, usulda musiqiy notalarni yaratilishi tahlil qilingan. L –tizimlar yordamida belgilar notalar ketma-ketligi sifatida talqin qilingan. Ushbu yondashuv grafik fraktal asosida L-tizimlarning musiqiy talqini hisoblanadi.

Musiqa odatda turli akustik chastotalar (balandlik, tovushlar)dagi tovushlarning muayyan tartibda ketma-ket joylashuvi (ya’ni melodiya), tovushlarning birgalikdagi uyg‘unligi (garmoniya) va vaqt bo‘yicha ketma-ket tashkil etilishi (ritm) sifatida tariflanadi [2].

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Alohida bir tovush (yoki balandlik) musiqa hosil qilmaydi; aslida, melodiya (balandlikning ketma-ket o‘zgarishi) va ritm (tovush davomiyligining ketma-ket o‘zgarishi) — musiqaning ikki asosiy elementi hisoblanadi.

O‘rta asrlarda numerologlar (sonlar falsafasi bilan shug‘ullanuvchilar) garmoniya bilan bog‘liq notalarning arifmetik munosabatlari haqida keng fikr yuritishgan. Ming yillar avvaldan ma’lumki, 2:1 chastota nisbati bo‘lgan notalar bir oktavani hosil qiladi.

15-asrdan 17-asrgacha musiqa va intonatsiya (sozlash) bilan bog‘liq ko‘plab nazariy va eksperimental ishlar bajarilgan. Masalan, oktavani bo‘lishda eng mashhur va amaliy usullardan biri — bu barcha kalitlarda garmoniyali tarzda asar ijro etish uchun ishlatiladigan "teng temperatsiya" (equal temperament) qoidasi hisoblanadi [1,2].

So‘nggi yillarda musiqa tuzilmasining tahlili shuni ko‘rsatadiki, u tabiiy manzaralardagi shakllarga o‘xshash uzoq masofali o‘lchov xossalariga ega bo‘lishi mumkin (masalan, tog‘lar profili, qirg‘oq chiziqlari va h.k.) [3].

Voss va Clarke [4,5] tomonidan turli uslublardagi (klassik, rok, jazz, blyuz) musiqalarning audio signallari ustida quvvat spektri tahlili bajarilib, quyidagi natijalar aniqlangan:

- Tovush balandligi va chastota tebranishi (ya’ni melodiya) signalining quvvat spektri taxminan 1/f qonuniga bo‘ysunadi.
- Bu turdagi spektr — fraktal shovqin, elektron qurilmalarda ham uchraydi [6,7].
- Bu xulosalarni Shroeder [8] va Kempbell [9] ham tasdiqlagan. Ularning tadqiqotlari musiqada uslub va asarga qarab o‘zgaruvchi uzoq masofali korrelyatsiya mavjudligini ko‘rsatadi.

1/f spektrli musiqa shovqini shunchaki tasodifiy emas:

- $1/f^0$ — ya’ni tasodifiy shovqin, ma’nosiz eshitiladi.
- $1/f^2$ — ya’ni Braunov shovqin, haddan tashqari zerikarli tuyuladi [10].
- 1/f spektr esa:
- Tasodifiylik va tartiblilikning optimal muvozanatini beradi.
- Qo‘shni signal qiymatlari o‘rtasida kuchli bog‘liqlik (korrelyatsiya) mavjud.
- Shu sababli, 1/f shovqinli signal – stoxastik musiqa kompozitsiyasi uchun mukammal asos bo‘ladi [12–15].

L-tizim

1960-yillarda Aristid Lindenmayer biologik tizimlarda o‘sish jarayonlarini modellashtirish uchun parallel grafik grammatikalardan foydalanishni taklif etdi [LINDEN68]. Bu grammatikalar "Lindenmayer tizimlari" yoki qisqacha "L-tizimlar" deb ataladi.

Alvy Ray Smith o‘zining SIGGRAPH maqolasida graftallar (ya’ni o‘simliklarga o‘xshash grafik tuzilmalar) orqali kompyuter grafikasida L-tizimlarning qo‘llanishini tasvirlab bergan [SMITH84].

“L” harfi oldidan kelgan raqam ushbu tizimning kontekstga sezuvchanlik darajasini bildiradi:

L-tizimlarning bir nechta turlari kiritiladi. Ular quyidagi tartibda ko‘rib

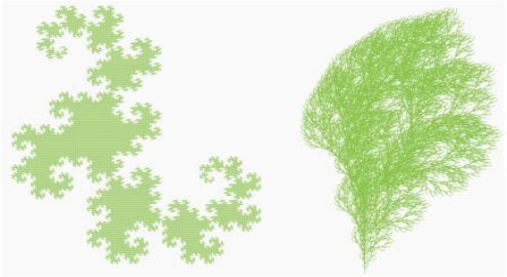
chiqiladi:

- Kontekstsiz L-tizimlar (Context-free L-Systems)
- Kontekstga bog‘liq L-tizimlar (Context-sensitive L-Systems)
- Stoxastik yoki no-deterministik L-tizimlar (Stochastic / Non-
- deterministic L-Systems)
- Deterministik L-tizimlar (Deterministic L-Systems)
- Tarbiyalovchi L-tizimlar (Propagative L-Systems)
- Tarbiyalovchi bo‘lmagan L-tizimlar (Non-propagative L-Systems)
- Jadval asosidagi L-tizimlar (Table L-Systems)
- Parametrik L-tizimlar (Parametric L-Systems)

Bu usulda L-tizim alifbosidagi harflar grafik harakatlarga moslashtiriladi, ya’ni “toshbaqa” deb ataluvchi grafik agent ushbu belgilar orqali boshqariladi.

- F – toshbaqa’ni uzunligi d ga teng masofaga oldinga harakatlantiradi va nuqtalar (x,y)(x, y)(x,y) va (x′,y′)(x', y')(x′,y′) orasiga chiziq chizadi.
- f – toshbaqa’ni uzunligi d ga teng masofaga oldinga harakatlantiradi, lekin chiziq chizmaydi.
- + – toshbaqa’ni chapga buradi, burilish burchagi +δ bo‘ladi.
- – – toshbaqa’ni o‘ngga buradi, burilish burchagi –δ bo‘ladi.
- [– toshbaqa’ning joriy holatini (x, y, α) saqlaydi.
-] – oldin saqlangan toshbaqa holatini qayta tiklaydi (pop qiladi).

Oddiygina ishlab chiqarish qoidalari (produksiya qoidalari) orqali ham o‘simliklar yoki barglarga o‘xshash juda qiziqarli va estetik chizmalar hosil qilish mumkin.Shuningdek, fraktal shakllarni ham chizish mumkin.



1-rasm – L-tizimlarning grafik talqinlariga misollar (muallif tomonidan yaratilgan). Chap tarafdagi rasm:Bu Dragon Curve (Ajdaho egri chizig‘i) bo‘lib, o‘z-o‘ziga o‘xshash fraktal shakl hisoblanadi. Qadamlar soni: 15 Aksioma: FX Produksiya qoidalari: X → X+YF+Y → –FX–Y δ (burchak): 90 daraja O‘ng tarafdagi rasm: Bu butaga (butazorga) o‘xshash o‘simlik tasviri. Qadamlar soni: 5 Aksioma: ++++F Produksiya qoidasi: F → FF–[–F+F+F]+[+F–F–F] δ (burchak): 22.5 daraja

IFS (Takrorlanuvchi funksiya tizimlari)

IFS fraktali (Takrorlanuvchi funksiya tizimlari) — bu geometrik shakl bo‘lib, u o‘zining kichikroq qismlaridan tashkil topgan va har bir qismi butun shaklning kichik nusxasidir. Ular o‘z-o‘ziga o‘xshashlik (self-similarity) tamoyiliga asoslangan. Fraktallarni yaratishda ko‘p martalik transformatsiyalar (masalan, masshtablash, aylantirish, siljitish) takroran qo‘llaniladi.

IFS fraktali musiqada — bu musiqiy naqshlarni iteratsion usulda o‘zining kichik versiyalariga bo‘lib, har bir versiyani transformatsiya qilish orqali yaratish jarayonidir.

2-rasm. Barnsley paporotnigi

Sintizator Generativ musiqa yaratish algoritmi sifatida IFS (iterated function system) — ya'ni takroriy funksiyalar tizimi asosida qurilgan fraktallardan foydalanadi. Ushbu algoritm aslida tasvirlar, masalan, paporotnik bargi shaklini hosil qilish uchun qo'llaniladi va u x, y koordinatalar juftligini ishlab chiqaradi. Bu koordinatalar aynan ohang (pitch) va davomiylik (duration) kabi musiqa elementlariga aylantirish uchun juda qulaydir.

Chunki bu generativ musiqa bo'lib, sintizator har safar yoqilganda avtomatik tarzda musiqa chalishni boshlaydi. Loyihaning keyingi bosqichida ushbu sintizatorni Arduino sensorlari orqali boshqariladigan, shuningdek, G'arb musiqasiga xos bo'lgan ohanglar (Western Music pitches) asosida ishlaydigan holga keltirish mumkin.

Brown harakati

Brown harakati — bu zarrachalarning suyuqlik yoki gaz muhitida tasodifiy va doimiy harakatidir. Ushbu hodisa fizikada tasodifiy jarayonlar modellashtirishda qo'llaniladi va matematikada stoxastik (tasodifiy) yurish deb qaraladi.

Fraktal musiqada Brown harakati tasodifiylik, doimiylik va o'z-o'ziga o'xshashlik (self-similarity) xususiyatlari bilan ahamiyatli rol o'ynaydi.

- Brown harakati asosida nota balandligi (pitch) tasodifiy, lekin silliq va doimiy o'zgarib turadi.
- Har bir keyingi nota avvalgisiga yaqin bo'ladi, ya'ni juda keskin sakrashlar bo'lmaydi (bu "fraktal" doimiylik hissi beradi).
- Brown harakati yordamida yaratilgan musiqalar ko'pincha tonal markaz atrofida aylanadi, bu esa garmoniklikni saqlaydi.
- Bu xatti-harakat G'arb musiqasi tamoyillariga yaqinlashadi.
- Brown musiqasi ko'pincha 1/f spektrga ega (ya'ni fraktal spektr), bu tabiiy tovushlar va musiqalarda keng uchraydi.
- Bu spektroga ega musiqalar odamlar uchun yoqimli va quloqqa oson qabul qilinadi.

Qiyosiy tahlil

1. L-tizim: strukturaviy, tarmoqlanuvchi musiqalar uchun eng qulay model. O'qitiladigan qoidalarga asoslanadi.
2. IFS: geometrik uyg'unlik va o'z-o'ziga o'xshashlikni aks ettirgan musiqalar yaratish uchun foydali. Ijodiy, ixcham hisoblanadi.

Brown harakati: tasodifiylikka asoslangan ohang oqimlari yaratish uchun ishlatiladi. Barqarorlik va tasodifiylik uyg'unlashgan musiqalar hosil qiladi.

3. Xulosa

Fraktal nazariyasining musiqaga tatbiqi zamonaviy algoritmik kompozitsiya jarayonlariga yangi turtki berib, musiqa yaratishda matematik modellashtirish imkoniyatlarini kengaytiradi. Tadqiqot davomida o'z-o'ziga o'xshashlik, iteratsiya va fraktal geometrik tuzilmalar asosida musiqa shakllarining strukturaviy xususiyatlari L-tizimlar, IFS (Iterated Function Systems) va Brown harakati kabi modellarning ohang (pitch), ritm va vaqt oralig'i (duration) bilan bog'liq aspektlari tahlil qilindi.

Fraktal nazariyasi asosida musiqiy kompozitsiyalarda tabiiylik, balans va tasodifiylikni uyg'unlashtirgan holda, san'at va matematikaning integratsiyalashgan yondashuvini yaratadi.

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