



Andrei P. Kirilyuk

Institute of Metal Physics, Kiev, Ukraine

<http://myprofile.cos.com/mammoth>



UNREDUCED DYNAMIC COMPLEXITY

**Towards the Unified Science
of Intelligent Communication
Networks and Software**



ICT COMPLEXITY AGENDA

- **Autonomic communication as a complex-dynamic interaction process**
Unreduced, user-oriented interaction
- **Universal science of complexity**
Real world dynamics, from particles to consciousness
- **Exact science of intelligent ICT**
Neither reduced “models”, no ambiguous “philosophy”
- **Practical applications and perspectives**

Complex Dynamics of Knowledge-Based Networks and the Intelligent Communication Paradigm

- User-oriented communication = unreduced interaction
- Unreduced interaction analysis: permanent chaotic, fractally structured realisation change → universal dynamic complexity
exceeds usual "science of complexity" (fractured, no complexity definition)
- Classification of dynamic regimes (more regular or chaotic)
and transitions between them
- Intrinsic chaos is inevitable in intense communication:
unreduced communication complexity
FRACTAL ↓ FRACTAL
Exponentially high efficiency instead of network failures
- Universal evolution law (direction of development):
what can happen and how to control it

Complex Dynamics of Knowledge-Based Networks and the Intelligent Communication Paradigm

- Universal concept of dynamic complexity and its successful applications to various systems:

<http://arxiv.org/find/quant-ph,gr-qc,physics/1/au:+Kirilyuk/0/1/0/all/0/1>

- Unreduced communication dynamics is as complex as transmitted information content ("life semantics"):
complexity correspondence principle



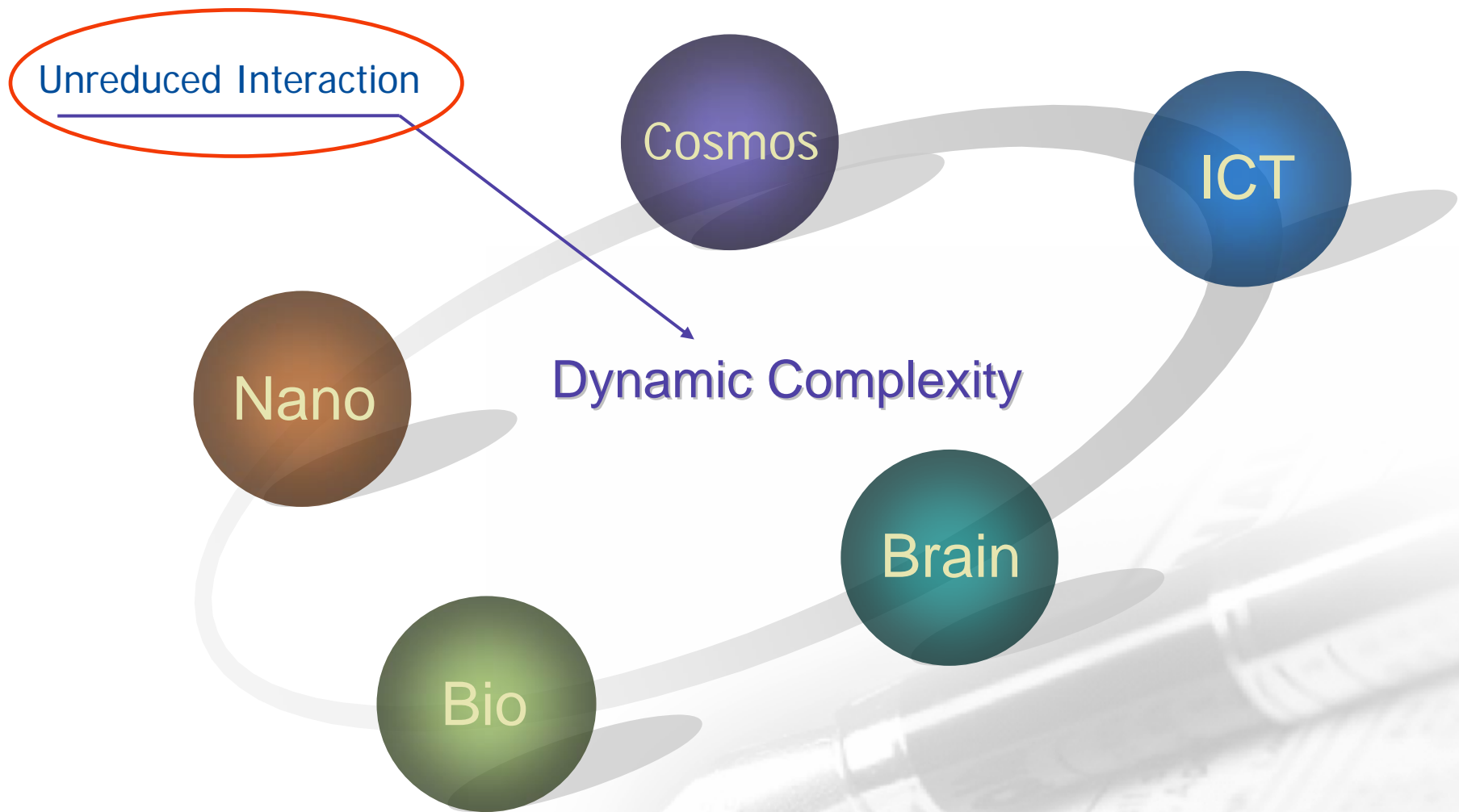
knowledge-based networks, complexity growth



- Principle and method of practical design and use of intelligent communication networks
 - Natural inclusion of all man-related aspects
true intelligence and consciousness, physics/0409140

FUNDAMENTAL, RIGOROUSLY DERIVED MEANING AND PURPOSE
OF AUTONOMIC COMMUNICATION AND RELATED INITIATIVES

Universal Science of Complexity



Science Progress Diagram

NEW MATHEMATICS OF COMPLEXITY

Unitary science: only one from many real system realisations

Universal Science of Complexity (USciCom): all system realisations

Unitary 1

Unitary 2

USciCom

Mechanistic
discreteness:
Numbers
Classical figures
No interaction
No change
No quality

Mechanistic
continuity:
Calculus
Deformable shapes
Trivial interaction
Formal change
No quality

Dynamic
discreteness:
Multivaluedness
Dynamical fractal
Full interaction
Intrinsic change
Full quality

Unreduced Interaction Dynamics

Arbitrary many-body interaction process:

$$\left\{ \sum_{k=0}^N \left[h_k(q_k) + \sum_{l>k}^N V_{kl}(q_k, q_l) \right] \right\} \Psi(Q) = E \Psi(Q), \quad Q = (q_1, q_2, \dots, q_N)$$

or

$$\left\{ h_0(\xi) + \sum_{k=1}^N \left[h_k(q_k) + V_{0k}(\xi, q_k) + \sum_{l>k}^N V_{kl}(q_k, q_l) \right] \right\} \Psi(\xi, Q) = E \Psi(\xi, Q), \quad \xi \equiv q_0$$

The unreduced (nonperturbative) general solution is always *probabilistic* (phenomenon of *dynamic multivaluedness* = *intrinsic chaoticity*):

$$\rho(\xi, Q) = \sum_{r=1}^{N_{\mathfrak{R}}} \oplus \rho_r(\xi, Q)$$

Dynamically determined probability

$$\alpha_r = \frac{N_r}{N_{\mathfrak{R}}}, \quad \sum_r \alpha_r = 1$$

Unreduced Interaction Dynamics

Arbitrary interaction process in terms of (free) component eigenvalues:

$$h_0(\xi)\psi_n(\xi) + \sum_{n'} V_{nn'}(\xi)\psi_{n'}(\xi) = \eta_n\psi_n(\xi)$$

where the total system state-function is obtained as

$$\Psi(\xi, Q) = \sum_{n \equiv (n_1, n_2, \dots, n_N)} \psi_n(q_0)\varphi_{1n_1}(q_1)\varphi_{2n_2}(q_2)\dots\varphi_{Nn_N}(q_N) \equiv \sum_n \psi_n(\xi)\Phi_n(Q)$$

Usual perturbative approximations:

$$\left[h_0(\xi) + V_{nn}(\xi) + \tilde{V}_n(\xi) \right] \psi_n(\xi) = \eta_n \psi_n(\xi), \quad V_0(\xi) < \tilde{V}_n(\xi) < \sum_{n'} V_{nn'}(\xi)$$

Unreduced general solution of the same problem:

$$\rho(\xi, Q) \equiv |\Psi(\xi, Q)|^2 = \sum_{r=1}^{N_{\mathfrak{X}}} \oplus \rho_r(\xi, Q), \quad \rho_r(\xi, Q) = |\Psi_r(\xi, Q)|^2$$

$$\Psi_r(\xi, Q) = \sum_i c_i^r \left[\Phi_0(Q) \psi_{0i}^r(\xi) + \sum_{n, i'} \frac{\Phi_n(Q) \psi_{ni'}^0(\xi) \int d\xi' \psi_{ni'}^{0*}(\xi') V_{n0}(\xi') \psi_{0i}^r(\xi')}{\Omega_\xi \eta_i^r - \eta_{ni'}^0 - \epsilon_{n0}} \right]$$

where $\{\psi_{0i}^r(\xi), \eta_i^r\}$ are eigen-solutions of the *effective* equation

$$h_0(\xi) \psi_0(\xi) + V_{\text{eff}}(\xi; \eta) \psi_0(\xi) = \eta \psi_0(\xi)$$

$$V_{\text{eff}}(\xi; \eta_i^r) \psi_{0i}^r(\xi) = V_{00}(\xi) \psi_{0i}^r(\xi) + \sum_{n, i'} \frac{V_{0n}(\xi) \psi_{ni'}^0(\xi) \int d\xi' \psi_{ni'}^{0*}(\xi') V_{n0}(\xi') \psi_{0i}^r(\xi')}{\Omega_\xi \eta_i^r - \eta_{ni'}^0 - \epsilon_{n0}}$$

Elementary length $\Delta x = \lambda = \Delta \eta_i^r$, time $\Delta t = \Delta x / v_0$, action $\Delta \mathcal{A} = V_{\text{eff}} \Delta t$

Unreduced Interaction Complexity

UNIVERSAL DEFINITION OF DYNAMIC (INTERACTION) COMPLEXITY:

$$C = C(N_{\mathfrak{R}}), \quad \frac{dC}{dN_{\mathfrak{R}}} > 0, \quad C(1) = 0$$

where $N_{\mathfrak{R}}$ is the (dynamically derived) *system realisation number*
for example: $C = C_0 \ln(N_{\mathfrak{R}})$, $C = C_0(N_{\mathfrak{R}} - 1)$, etc.

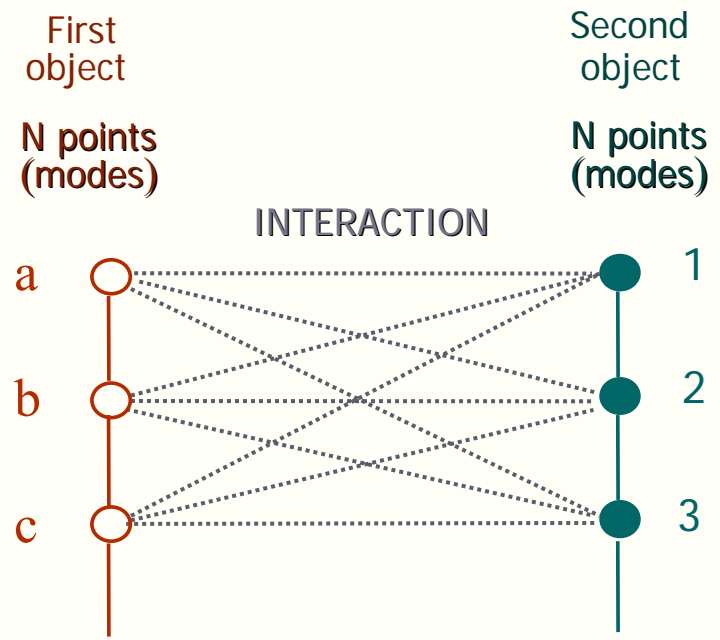
Universal dynamic complexity includes intrinsic *chaoticity*
due to the *dynamically probabilistic* problem solution:

$$\rho(\xi, Q) = \sum_{r=1}^{N_{\mathfrak{R}}} \oplus \rho_r(\xi, Q)$$

with the *dynamically determined probability*

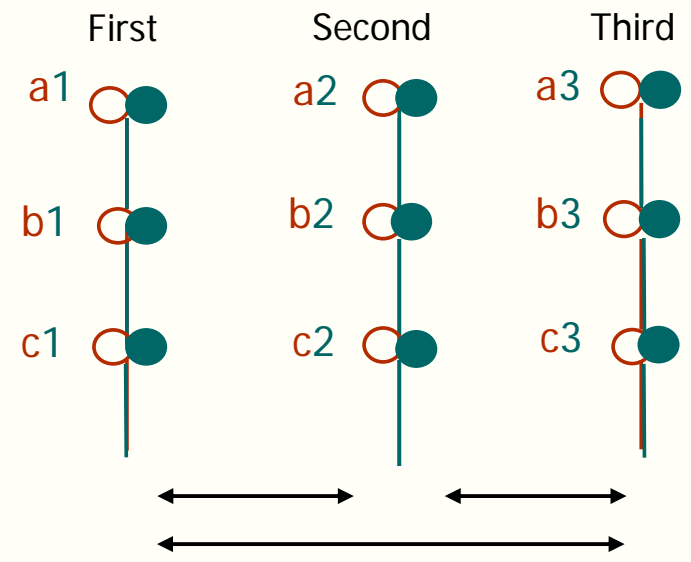
$$\alpha_r = \frac{N_r}{N_{\mathfrak{R}}}, \quad \sum_r \alpha_r = 1$$

Unreduced Interaction: Dynamic Multivaluedness (Chaos)



($N \times N$) combinations of mode entanglement
(**a1, a2, a3, b1, b2**, etc.)
↓
N-fold redundancy

Dynamically redundant interaction result:
incompatible system realisations



Permanent realisation change
in *causally (dynamically) random* order

Universal Regimes of Complex Dynamics

Two limiting regimes of complex dynamics:
multivalued self-organisation/SOC and uniform (global) chaos

Universal criterion of global (strong) chaos:

$$\kappa \equiv \frac{\Delta\eta_i}{\Delta\eta_n} = \frac{\omega_\xi}{\omega_Q} \approx 1$$

or *resonance* of the main system motions

Criterion of quasi-regularity (self-organisation): $\kappa \ll 1$ (or $\kappa \gg 1$)

As network intensity grows one *cannot avoid resonance* ("jam"): $\kappa \sim 1$
and therefore *essential dynamic randomness becomes inevitable*

Highly complicated interaction networks cannot be close to regularity
Ordinary, unitary dynamic models and approaches are inapplicable

Let's transform the unitary approach *defect* (system failure)
into the unreduced, complex-dynamic operation *advantage* :
superior power and qualities

Complex-Dynamic Network Properties

Huge efficiency growth of dynamically chaotic (*multivalued*) networks:
Chaotic network efficiency is determined by the number of *all combinations of links*

$$N! \approx \sqrt{2\pi N} (N/e)^N \sim N^N \propto C \text{ (unreduced dynamic complexity)}$$

where the number of links N is very large itself

Unitary (regular) dynamic efficiency grows only as N^β ($\beta \sim 1$).

The huge advantage in efficiency expresses *intrinsic creativity/adaptability* of the unreduced complex dynamics obtained at the expense of its *chaoticity*



INTELLIGENT, TRULY AUTONOMOUS COMMUNICATION PARADIGM

Particular aspects and applications

- (1) Knowledge-based structure of intelligent communication networks
- (2) Holistic, two-layer dynamics of **advanced** intelligent network ("superbrain")
Complex-dynamic meaning of *true* intelligence/consciousness (physics/0409140)
- (3) Intelligent network and its users *automatically* become more intelligent
Intrinsically suited to complex-dynamic problem solution → *revolution of complexity*
- (4) Universal symmetry/development of complexity: unified guiding principle
Transformation of *dynamic information* ("interaction potential") into *dynamic entropy*

Evolution as complexity development

UNIVERSAL MEANING AND CRITERION OF PROGRESS

- System evolution as a result of the symmetry of complexity: qualitative, irreversible, dynamically discrete (quantized) change (event): transformation of dynamic information, I , into dynamic entropy, S , while the sum, total complexity, $C = I + S$, remains unchanged:

$$\Delta C = 0, \quad \Delta S = -\Delta I = -\Delta \mathcal{A} > 0,$$

where the extended, nonlinear action $\mathcal{A} = I$ is a unified measure of complexity-information, $|\Delta \mathcal{A}| \sim |V_{\text{eff}}| \Delta t$

- Generalised Hamilton-Jacobi and Schrödinger equations:

$$\frac{\Delta \mathcal{A}}{\Delta t} \Big|_{x=\text{const}} + H \left(x, \frac{\Delta \mathcal{A}}{\Delta x} \Big|_{t=\text{const}}, t \right) = 0, \quad \hat{H} \left(x, \frac{\Delta}{\Delta x} \Big|_{t=\text{const}} \right) \Psi(x) = E \Psi(x)$$

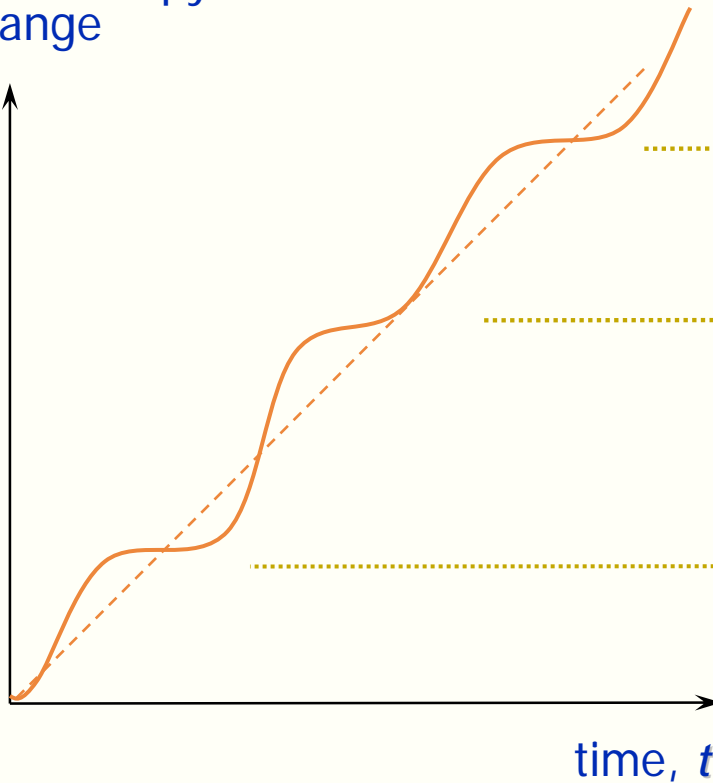
- The universal meaning and purpose of any system evolution, progress, and existence: complexity development as a result of the symmetry of complexity → teleological, purposeful dynamics

Progress by complexity steps

DYNAMICALLY DISCRETE COMPLEXITY DEVELOPMENT

dynamic entropy
change

$-\Delta I, \Delta S$



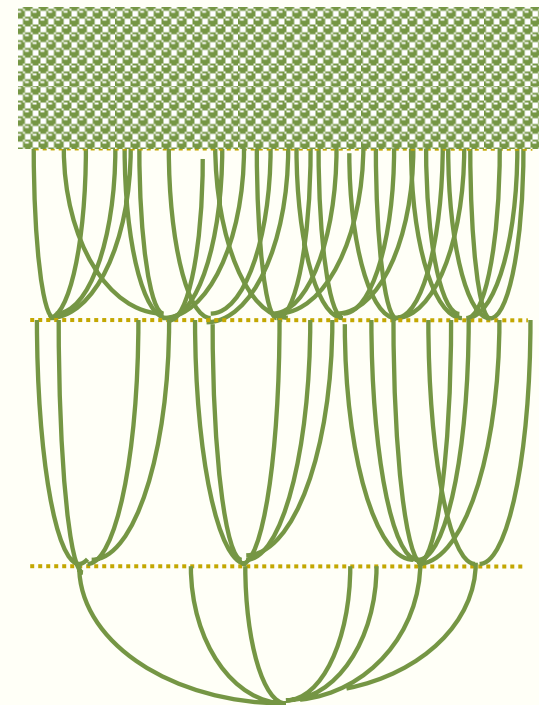
Fractal hierarchy of complexity

$n = 3$

$n = 2$

$n = 1$

Complexity
levels, n



Any structure creation is a growth of complexity-entropy

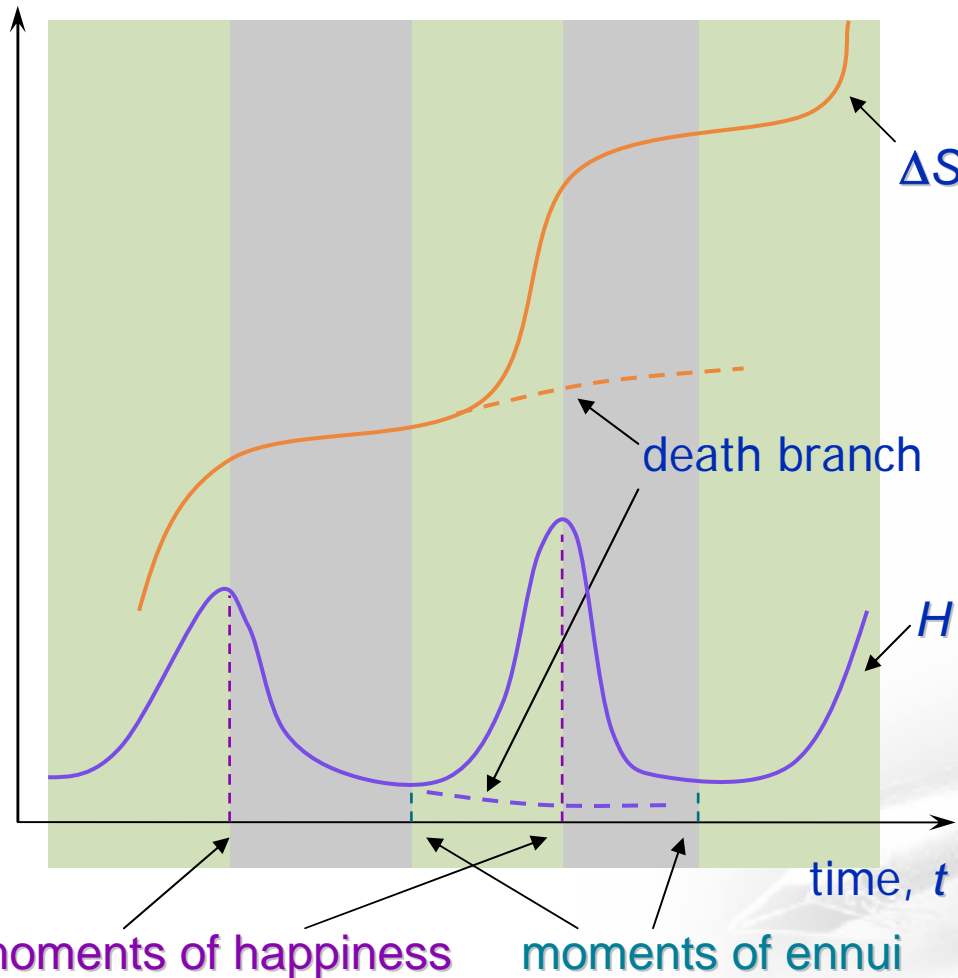
“progress” vs “decline”

dynamic entropy change, ΔS ,
Hamiltonian (energy), $\Delta S/\Delta t = H, E$

period of
progress



period of
decline



For both “progress” and “decline”:

$$H = \partial S / \partial t > 0$$

Progressive development (creation):

$$W = \partial H / \partial t = \partial^2 S / \partial t^2 > 0$$

Decline (decay, degradation):

$$W = \partial H / \partial t = \partial^2 S / \partial t^2 < 0$$

Max progress results (“happiness”):

$$\partial H / \partial t = \partial^2 S / \partial t^2 = 0, \quad \partial^2 H / \partial t^2 < 0$$

Max decay results (“ennui”):

$$\partial H / \partial t = \partial^2 S / \partial t^2 = 0, \quad \partial^2 H / \partial t^2 > 0$$

Transition *max* (“moment of truth”):

$$\partial^2 H / \partial t^2 = 0, \quad \partial^3 H / \partial t^3 < 0$$

Decline crisis (“moment of sin”):

$$\partial^2 H / \partial t^2 = 0, \quad \partial^3 H / \partial t^3 > 0$$

Universal complexity in action

UNREDUCED COMPLEXITY APPLICATIONS

- Unified, causally complete fundamental physics (quantum mechanics, relativity, particles, fields, forces, cosmology): no “mysteries”, transparent, realistic knowledge and world view, the unique way to unlimited clean energy
- Real, complex-dynamic nanodevices (quantum & classical), huge efficiency
- Causally complete, reliable genomics (unreduced interaction dynamics)
- Complex-dynamic biology: causal evolution theory, integral medicine
- Creative ecology/development: realistic, unreduced sustainability concept
- Emerging genuine intelligence and consciousness (natural and artificial)
- Complex-dynamic, intelligent communication networks and software systems

COMPLEX-DYNAMIC ICT PERSPECTIVES

- Intelligent, truly autonomic, user-oriented communication and software tools: superior quality of services and operation power
- Essential, “built-in” progress of user capacities: intrinsic intelligence coevolution without painful “upgrades”, “system failures”, and “digital divide”
- Super-efficient and terribly interesting “global ICT game” or “real virtual reality”

<http://arxiv.org/find/quant-ph,gr-qc,physics/1/au:+Kirilyuk/0/1/0/all/0/1>

New mathematics of complexity

PROPERTIES OF UNREDUCED PROBLEM SOLUTION

- *Non*-uniqueness of any real problem solution: universal *dynamic multivaluedness*
- Explicit dynamic *emergence*, origin of *events* and *time*: $A \neq A$ for any real A
- Fractally structured *dynamic entanglement*: *rigorous* expression of *material quality*
- No “exact solutions”: meaning of *randomness*, *nonintegrability*, *noncomputability*, etc.
- *Dynamic* discreteness (*causal quantisation*), *nonunitarity*, dynamic origin of *space*

Science Progress Diagram

NEW MATHEMATICS OF COMPLEXITY

Unitary science: only one from many real system realisations
Universal Science of Complexity (USciCom): all system realisations

Unitary 1

Unitary 2

USciCom

Mechanistic
discreteness:
Numbers
Classical figures
No interaction
No change
No quality

Mechanistic
continuity:
Calculus
Deformable shapes
Trivial interaction
Formal change
No quality

Dynamic
discreteness:
Multivaluedness
Dynamical fractal
Full interaction
Intrinsic change
Full quality

Unreduced complexity features

UNIVERSAL CONCEPT AND SCIENCE OF COMPLEXITY

- **Unreduced complexity >> usual imitations of complexity**
Fundamental difference of *unreduced complexity* (dynamic multivaluedness) from any dynamically single-valued (unitary) *imitations of complexity*
- **Usual science = zero-dimensional projection of reality**
The *whole* usual, unitary science, including scholar “science of complexity” (“chaos”, “self-organisation”, “nonlinear dynamics”, etc.), is the *simplest* possible, *zero-dimensional, point-like projection* of real, *multivalued* world dynamics
- **Unreduced complexity = natural completion of usual science**
Universal science of complexity (*unreduced* interaction problem *solution*) is the explicit, causally complete extension of the unitary science (from one system realisation to their complete set)
- **Problem-solving power of the universal science of complexity**
Unreduced complexity (dynamically multivalued solution) *solves stagnating problems* of unitary science (quantum physics, particles, field theory, gravity, cosmology, solid state, biology, etc.) and *completes* it up to the humanities (consciousness, ethics, aesthetics, development, etc.)
- **Complex system creation by unreduced complexity understanding**
Only the *unreduced* dynamic complexity is suitable for *real-world* applications involving *new system design* (like autonomic communication networks, intelligent software, AI, machine consciousness)



UNIFIED SCIENCE OF COMPLEX ICT SYSTEMS

Principles of Complex ICT System Operation & Design

- I. **Complexity correspondence principle**
Efficient interaction of comparable complexity units
- II. **Complex-dynamic control principle**
Complexity development as the purpose of control
- III. **Unreduced (free) interaction principle**
Huge power of unreduced interaction complexity

UNIFIED BY THE **SYMMETRY OF COMPLEXITY**



Complexity Correspondence Principle

Efficient Interaction of Comparable Complexity Units

- ⌘ Higher complexity enslaves lower complexity
Low complexity **cannot** control/simulate high complexity
→ **only unreduced complexity** tools for context-based ICT
- ⌘ Similar complexities give rise to strong chaoticity
Creative power of “confined” chaos (dynamic adaptability)
- ⌘ Excessive complexity tool replaces useful operation
Complex tools at context/software, **not** traffic/hardware level



Complex-Dynamic Control Principle

Complexity Development as Unified Control Purpose

- ❧ **Controlled dynamics cannot be totally regular**
Relying upon usual “total” control gives **total system failure**
Multivalued, chaotic SOC regime is a general control result
- ❧ **Optimal interaction complexity development**
Creative, rather than restrictive control is **more** reliable
- ❧ **Universal guiding line and criterion of control**
Sustainable control: global stability by local creativity



Unreduced (Free) Interaction Principle

Huge Power of Unreduced Interaction Complexity

- ⌘ **General purpose of complexity-entropy growth**
Only general direction is fixed/controlled, not the details
Intrinsic chaoticity is a normal, useful system state
- ⌘ **Huge power of unreduced complex dynamics**
Genuine parallelism of multivalued dynamical fractal
- ⌘ **Constructive alternation of strong chaos and SOC**
Symmetry of complexity: chaotic search and ordered creation



COMPLEXITY TRANSITION IN ICT SYSTEMS

The New Era of Intelligent Communication Tools

- (1) Transition to useful dynamic complexity/chaos**
Priority R&D task and inevitable way of development
- (2) Complexity levels of global communication system**
 - Quasi-regular P2P network (modern internet, phone)
 - Complex-dynamic P2P network (liberated internet)
 - Context-based network: “human” complexity levels
- (3) Intelligent and conscious communication systems**
Unified, fractal “quantum beat” (physics/0409140)
Unlimited coevolution of system and user complexity

Knowledge-Based Structure of Intelligent Communication Networks

Realistic initiation of intelligent networks

- ✿ Existing networks are based on *hardware* tools
regular control, rigid structure, nonintelligent behaviour
inevitable first step of development (now accomplished)
- ✿ *Knowledge*, not tools, is the network purpose
very limited solution by "advanced" search tools (Google)
- ✿ *Knowledge-based network* is the next step
structure guided by (developing) user knowledge (P2P)
permanently changeable, irregular, autonomously adaptable
complex-dynamic interaction, intelligent network
mathematical structure of probabilistic dynamic fractal

Knowledge-Based Structure of Intelligent Communication Networks

- ✿ Full solution needs qualitatively new tools

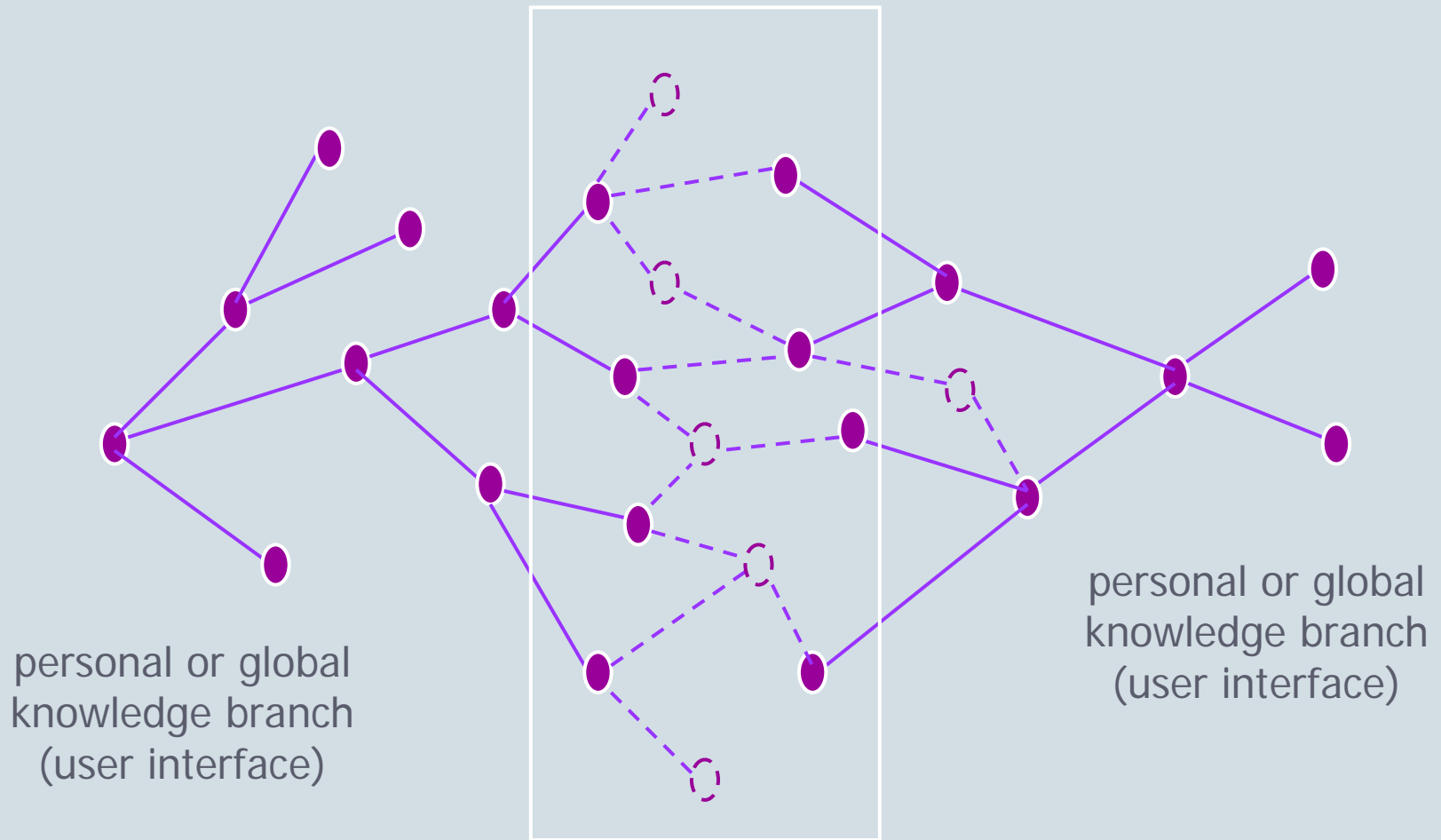
Three levels of complex network dynamics:

- (1) restricted user complexity (today)
- (2) user-oriented software complexity (local intelligence)
- (3) hardware dynamic complexity (global intelligence)

- ✿ A reduced solution (2) is a feasible next step
hierarchic, knowledge-guided structure of software
“tree of knowledge” in the web and user tools (interface)
permanent interaction and autonomous change

- ✿ A reduced solution prepares the full solution (3)
mechanical “intelligence” as a way to genuine intelligence
users of intelligent network become more intelligent
knowledge-based network supports its own development

Knowledge-Based Structure of Intelligent Communication Networks

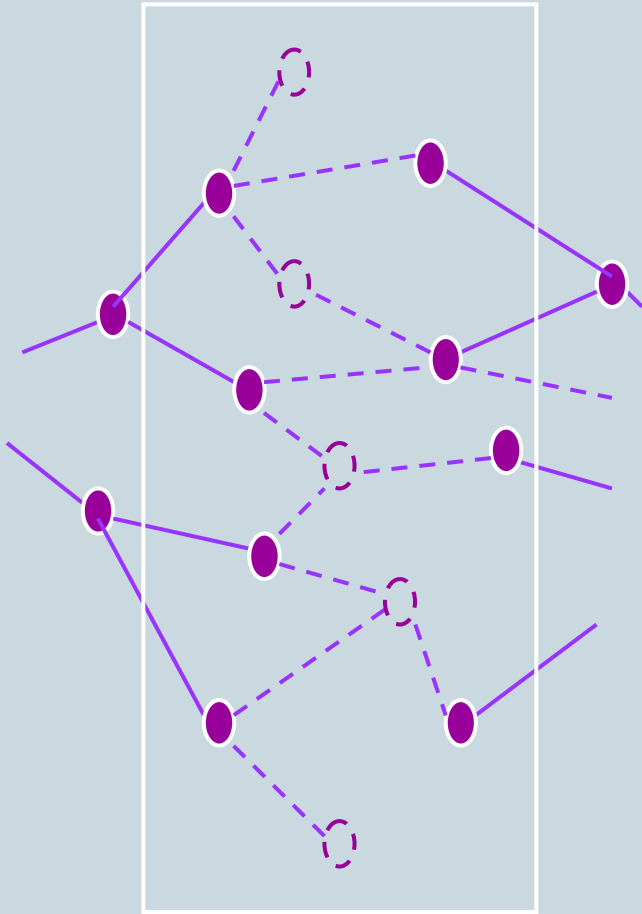


personal or global
knowledge branch
(user interface)

personal or global
knowledge branch
(user interface)

autonomous development
due to complex-dynamic branch interaction

Knowledge-Based Structure of Intelligent Communication Networks



Principles of complex network realisation

- (1) Available "interaction space"
 - (2) Self-amplifying (chaotic) interaction rule
 - (3) Based on the unreduced complexity and "complexity correspondence principle"
- ↓
- Universal criterion of intelligent operation

branch interaction process

Sustainable communication

- **Today's communication development is *not* sustainable:**
quickly *growing problems* of intensity, content, efficiency, creativity (similar to usual ecological problems) → we need always more
- **Illusion of regularity:**
regular, "industrial" operation mode inevitably leads to *degradation* at a high intensity stage (similar to usual developed industry)
- **Illusion of power:**
power *cannot* increase *quality* by itself: increasing power capacities need another, qualitatively different dynamics → complexity
- **Only complex-dynamic communication can be sustainable:**
 - *system freedom* to change its own structure (true autonomy)
 - efficient management of *information content* (intelligence)
 - *complex-dynamic* (chaotic) control → genuine security and *progress*
 - *permanent, natural* user-machine-network complexity *coevolution*
- **Today's bifurcation of communication development:**
Complexity Transition = Sustainability Transition (similar to ecology)

ICT complexity perspectives

- *Only* unreduced complexity has *unlimited* development perspectives: *social* aspects
- Understanding of unreduced complexity is essential also for its *efficient imitations*
- The unique, practically important case of *artificial* dynamic complexity: important connection to *natural* complexity studies
- The unique possibility for the new progress of *fundamental science* (otherwise “ending”)

Universal complexity in action

UNREDUCED COMPLEXITY APPLICATIONS

- Unified, causally complete fundamental physics (quantum mechanics, relativity, particles, fields, forces, cosmology): no “mysteries”, transparent, realistic knowledge and world view, the unique way to unlimited clean energy
- Real, complex-dynamic nanodevices (quantum & classical), huge efficiency
- Causally complete, reliable genomics (unreduced interaction dynamics)
- Complex-dynamic biology: causal evolution theory, integral medicine
- Creative ecology/development: realistic, unreduced sustainability concept
- Emerging genuine intelligence and consciousness (natural and artificial)
- Complex-dynamic, intelligent communication networks and software systems

COMPLEX-DYNAMIC ICT PERSPECTIVES

- Intelligent, truly autonomic, user-oriented communication and software tools: superior quality of services and operation power
- Essential, “built-in” progress of user capacities: intrinsic intelligence coevolution without painful “upgrades”, “system failures”, and “digital divide”
- Super-efficient and terribly interesting “global ICT game” or “real virtual reality”

<http://arxiv.org/find/quant-ph,gr-qc,physics/1/au:+Kirilyuk/0/1/0/all/0/1>

References

- [1] A.P. Kirilyuk, "Complex Dynamics of Autonomous Communication Networks and the Intelligent Communication Paradigm", Report at the International Workshop on Autonomic Communication (Berlin, 18-19 Oct 2004), E-print physics/0412058 at <http://arXiv.org>.
- [2] A.P. Kirilyuk, "Emerging Consciousness as a Result of Complex-Dynamical Interaction Process", Report presented at the EXYSTENCE workshop Machine Consciousness: Complexity Aspects (Turin, 29 Sep - 1 Oct 2003), E-print physics/0409140 at <http://arXiv.org>.
- [3] A.P. Kirilyuk, "Dynamically Multivalued, Not Unitary or Stochastic, Operation of Real Quantum, Classical and Hybrid Micro-Machines", E-print physics/0211071 at <http://arXiv.org>.
- [4] A.P. Kirilyuk, *Universal Concept of Complexity by the Dynamic Redundance Paradigm: Causal Randomness, Complete Wave Mechanics, and the Ultimate Unification of Knowledge* (Kyiv: Naukova Dumka: 1997). For a non-technical review see also: E-print physics/9806002.
- [5] A.P. Kirilyuk, "Dynamically Multivalued Self-Organisation and Probabilistic Structure Formation Processes", *Solid State Phenomena* **97-98** (2004) 21-26. E-print physics/0405063.
- [6] A.P. Kirilyuk, "Universal Symmetry of Complexity and Its Manifestations at Different Levels of World Dynamics", *Proceedings of Institute of Mathematics of NAS of Ukraine* **50** (2004) 821-828. E-print physics/0404006 at <http://arXiv.org>.
- [7] A.P. Kirilyuk, "Complex-Dynamical Extension of the Fractal Paradigm and Its Applications in Life Sciences", In: G.A. Losa, D. Merlini, T.F. Nonnenmacher, and E.R. Weibel (Eds.), *Fractals in Biology and Medicine, Vol. IV* (Basel: Birkhäuser: 2005) 233–244. E-print physics/0502133.
- [8] A.P. Kirilyuk, "Complex Dynamics of Real Nanosystems: Fundamental Paradigm for Nanoscience and Nanotechnology", *Nanosystems, Nanomaterials, Nanotechnologies* **2** (2004) 1085–1090. E-print physics/0412097 at <http://arXiv.org>.